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Beyond the Quantum

'Quantum reality' versus 'quantum or reality?'

By James E. Beichler

There are probably as many opinions and interpretations of quantum theory as there are physicists and philosophers. The proliferation of so many different interpretations of so important an aspect of modern science as the quantum could be either good or bad for the progress of physics, depending on the scientist to whom you are speaking at any given time. The fact that quantum theory is open to so many interpretations poses serious questions regarding the fundamental nature of the basic concepts behind the quantum. On the other hand, as long as quantum theory continues to yield good results in the laboratory, many scientists are willing to overlook or ignore its fundamental flaws. However, the fundamental problems and flaws that have acted to foster the differing views of the quantum are a real and present danger for the theory itself as well as the present state of physics and science in general. Simple quantum mechanics and its various extensions have dominated theoretical and experimental physics so thoroughly for nearly the last century that any problems with the quantum worldview, whether explicit or implicit, affect all of physics and science.

There can be no doubt that the quantum theory has provided science with some of its most spectacular results. Scientist after scientist points out the fact that 'quantum electrodynamics' is thought of as the most accurate physical theory in all of history. Paul Davies states the case well even while pointing out one of the more specific problems with QED.

> The success of quantum electrodynamics in accounting for the results of experiment is remarkable, and agreement between theory and experiment to about 1 part in 100 million has been achieved in the case of the interaction between electrons and the electromagnetic field. For this reason alone, it may be assumed that the theory will last. Nevertheless, the presence of the infinite quantities which are formally removed by the renormalisation procedure is worrying. (Davies, #1, 189)

Praise for QED also comes from Roger Penrose who gives it a 'SUPERB' rating among present day scientific theories, the highest rating that he could bestow upon it.

> I am setting high standards for the category SUPERB, but this is what we have become accustomed to in physics. Now, what about the more recent theories? In my opinion there is only one of them which can possible qualify as SUPERB and this is not a particularly recent one: a theory called *quantum electrodynamics* (or QED), which emerged from the work of Jordan, Heisenberg, and Pauli, was formulated by Dirac in l926-1934, and made workable by Bethe, Feynman, Schwinger, and Tomonaga in 1947-1948. This theory arose as a combination of the principles of quantum mechanics with special relativity, incorporating Maxwell's equations and a fundamental equation governing the motion and spin of electrons, due to Dirac. The theory as a whole does not have the compelling elegance or consistency of the earlier SUPERB theories, but it qualifies by virtue of its truly phenomenal accuracy. A particularly noteworthy implication is the value of the magnetic moment of an electron. (Electrons behave like tiny magnets of spinning electric charge. The term 'magnetic moment' refers to the

> strength of this tiny magnet.) The value 1.00115965246 (in appropriate units - with an allowance for error of about 20 in the last two digits) is what is calculated from QED for this magnetic moment, whereas the most recent experimental value is 1.001159652193 (with a possible error of about 10 in the last two digits). As Feynman has pointed out, this kind of accuracy could determine the distance between New York and Los Angeles to within the width of a human hair! (Penrose, 1989, 153-154)

Penrose's example is more explicit than Davies'. He points out that QED was developed as a combination of quantum mechanics and special relativity (not a unification). He also points out that the theory does not have the "compelling elegance or consistency" of previous physical theories of the same caliber. In this manner, Penrose has addressed one of the major problems with QED.

In spite of the seemingly fantastic degrees of accuracy between values predicted by QED and the values measured in the laboratory, lingering problems are still evident within the theory, especially those already alluded to. In other words, the accuracy of QED comes at the very high price of 'renormalization,' a purely mathematical process that was developed without any prior physical basis. Both Davies and Penrose explicitly point out QED's shortcomings even though they are clearly aware of the experimental accuracy of QED. According to Davies,

> This technique of hiding the mathematically undesirable infinities is called *renormalisation,* and the resulting theory of quantum electrodynamics (QED), properly renormalised, turns out to be brilliantly successful (see Chapter 18). The infinities that arise in QED are symptomatic of nearly all quantum field theories, so that when physicists try to formulate theories of the other three forces of nature, the same mathematical problems occur. Unfortunately, the renormalisation of QED is by no means automatic, and only very recently has the technique begun to work for the other types of interactions. (Davies, #2, 200)

Penrose is not so kind in his own assessment of the renormalization problem, in spite of his rating of "SUPERB" for the theory as a whole.

> The supreme quantum field theory is 'quantum electrodynamics' - basically the theory of electrons and photons. This theory is remarkable for the accuracy of its predictions (e.g the precise value of the magnetic moment of the electron, referred to in the last chapter, p.153). However, it is a rather untidy theory - and a not altogether consistent one - because it initially gives nonsensical 'infinite' answers. These have to be removed by a process known as 'renormalization'. Not all quantum field theories are amenable to renormalization, and they are difficult to calculate with even when they are.
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> A popular approach to quantum field theory is via 'path integrals', which involve forming quantum linear superpositions not just of different particle states (as with ordinary wave functions), but of entire space-time histories of physical behaviour (see Feynman 1985, for a popular account). However, this approach has additional infinities of its own, and one makes sense of it only via the introduction of various 'mathematical tricks'. Despite the undoubted power and impressive accuracy of quantum field theory (in those few cases where the theory can be fully carried through), one is left with a feeling that deeper understandings are needed before one can be confident of any 'picture of physical reality' that it may seem to lead to.
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> I should make clear that the compatibility between quantum theory and special relativity provided by quantum field theory is only *partial-referring* only to U (a deterministic process of evolution) - and is of a rather mathematically formal nature. The

> difficulty of a consistent relativistic interpretation of the 'quantum jumps' occurring with R (the non-deterministic state-vector reduction), that the EPR-type experiments leave us with, is not even touched by quantum field theory. Also, there is not yet a consistent or believable quantum field theory of gravity. I shall be suggesting, in Chapter 8, that these matters may not be altogether unrelated. (Penrose, 1989, 289-290)

By noting these discrepancies between the accuracy and completeness of the theory, Penrose has pinpointed the problem that these "mathematical tricks" render QED and its successors bereft of any "deeper understandings" of the nature of physical reality. The lack of "deeper understandings" is endemic to the quantum theory as a whole, if for no other reason than due to the limits imposed on our knowledge of physical reality by the Heisenberg uncertainty principle.

Mendel Sachs, another well-known and respected physicist, is far harsher on QED as well as the overall concept of a 'quantum field theory' for which QED is the prime example.

> When the case of special relativity is evoked (it should also be subject to the rules of general relativity, in principle) we have quantum electrodynamics, when the interaction is electromagnetic. Generally the theory is called 'Relativistic Quantum Field Theory' (RQFT) for any type of interaction.
>
> The well known trouble with RQFT is that when its formal expression is examined for its solutions, it is found that it does not have any! This is because of infinities that are automatically generated in this formulation. After this failure of the quantum theory was discovered, renormalization computational techniques were invented that provide a recipe for subtracting away the infinities and thereby generating finite predictions--some which had amazing empirical success. But the trouble is that a) such a scheme is not demonstrably mathematically consistent (implying that, in principle, any number of predictions could come from the same physical situations, though one of them is empirically correct) and b) there still remains the problem that there are no finite solutions for the problem. Thus, if non-relativistic quantum mechanics is supposed to be not more than an approximation for RQFT, and if the latter does not exist as a mathematically (or logically) consistent theory, then we still do not have the right to claim the scientific truth of the bases of non-relativistic quantum mechanics (i.e. fundamental uncertainty and probability in laws of matter, linearity, 'open system', mathematical representation with a Hilbert space, etc.). **IT IS IMPORTANT TO KNOW THAT THE EMPIRICAL AGREEMENT WITH THE PREDICTIONS OF A SCIENTIFIC THEORY, WHILE BEING A NECESSARY REQUIREMENT FOR THE TRUTH OF THAT THEORY, IS NOT SUFFICIENT TO ESTABLISH ITS TRUTH**. To be a scientifically true theory, its expression must also be both logically and mathematically consistent. Unfortunately, RQFT is neither. (Sachs, 1997, Internet)

Sachs' philosophical approach to physics and physical reality is that of a 'field theoretician' as was Einstein's. In this regard, Sachs should be considered the closest and best example of an heir to Einstein's philosophical approach that can be found in science today. Other physicists are not quite as specific as either Penrose or Sachs, but criticize quantum theory nonetheless. They are also critical of those scientists who blindly accept modern quantum theory on the basis of its mathematical model and accurate results while disregarding the philosophical consequences associated with the quantum.

Many would argue that philosophical considerations have no real place in either the development or choice of physical theories, but their arguments could easily be demonstrated as inaccurate. Science cannot rely on the "development of mathematical equations" alone, but must reflect some philosophical worldview. This very point was well supported by David Bohm.

> It seems clear, then, that we are faced with deep and radical fragmentation, as well as thoroughgoing confusion, if we try to think of what could be the reality that is treated by our physical laws. At present physicists tend to avoid this issue by adopting the attitude that our overall views concerning the nature of reality are of little or no importance. All that counts in physical theory is supposed to be the development of mathematical equations that permit us to predict and control the behaviour of large statistical aggregates of particles. Such a goal is not regarded as merely for its pragmatic and technical utility: rather, it has become a presupposition of most work in modern physics that prediction and control of this kind is all that human knowledge is about.
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> This sort of presupposition is indeed in accord with the general spirit of our age, but it is my main proposal in this book that we cannot thus simply dispense with an overall world view. If we try to do so, we will find that we are left with whatever (generally inadequate) world views may happen to be at hand. Indeed, one finds that physicists are not actually able just to engage in calculations aimed at prediction and control: they do find it necessary to use images based on *some* kind of general notions concerning the nature of reality, such as 'the particles that are the building blocks of the universe'; but these images are now highly confused (e.g. these particles move discontinuously and are also waves). In short, we are here confronted with an example of how deep and strong is the need for *some* kind of notion of reality in our thinking, even if it be fragmentary and muddled. (Bohm, xiii-xiv)

In short, science devoid of a philosophical worldview, or some may say metaphysics, is at best "fragmentary and muddled." Some independent notion of reality is required beyond the "calculations aimed at prediction and control" of nature. Curiously enough, Ted Bastin has also referred to the situation represented by modern quantum theory as a "muddle." He described “disquiet" among physicists regarding the inconsistencies in quantum theory. "It is not now as easy as it was a quarter of a century ago to ignore the disquiet which many physicists have continued to voice about basic inconsistencies in the foundations of the quantum theory. This disquiet has been focused largely on what is called "the measurement problem" though this expression conceals muddled thought." (Bastin, 122)

Another physicist, Ian D. Lawrie, documents an uneasiness felt by physicists with regard to modern quantum theory although he has not clearly defined the cause of his concerns. He claims that modern physicists "do not properly understand what it is that quantum theory tells us about the nature of the physical world" even though "there are respectable scientists who write with confidence on the subject." Lawrie believes that "the conceptual basis of the theory is still somewhat obscure." (Lawrie, 95) He is not as hard on the theory as Sachs, but he does represent a growing and significant number of physicists who are concerned with the muddled state of modern physics. Undoubtedly, the priority of QED in modern quantum theory and the present use of quantum mechanics as the basis for the majority of physicists' conception of physical reality is in need of closer scrutiny.

Too many scientists and scholars take the good with the bad and then either ignore the bad features of quantum theory or discard them outright as irrelevant. This practice has now evolved into a clear and present danger for modern science because later and more advanced QFTs are based upon the experimental successes of QED and thus perpetuate QED's problems. Sachs places such problems within a much larger philosophical context and thereby draws specific lines of demarcation for considering the problems between quantum theory and relativity.

> It goes without saying that Quantum Mechanics has been one of the outstanding successes of twentieth century physics - in its correctly predicting and representing many of the atomic, nuclear and elementary particle phenomena. From the point of view of the Philosophy of Science, it is indeed a *necessary condition* for any valid scientific theory to meet that it should accurately predict the empirical data relating to particular physical phenomena, if it is to claim to be a (scientifically) true explanation for these phenomena. Nevertheless, it is important to recognize that this requirement is not a *sufficient condition* to establish its scientific validity. For a valid theory in science must also be (1) logically and mathematically consistent, and (2) it should be successful in its full spectrum of potential predictions; that is to say, if some of its predictions should be verified and others not, the entire theory should then be subject to question.
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> In spite of the outstanding numerical successes of quantum mechanics in fitting the data of elementary matter experimentation, it has not been able to meet the criteria of consistency and completeness mentioned above, at least to this date. As we will discuss in Chapter 2, the extension of nonrelativistic quantum mechanics to the relativistic domain, that is a necessary extension for the logical consistency of the theory, on its own terms, entails a breakdown of the essential logical and mathematical ingredients of the quantum theory, and indeed yields a mathematical formalism that has no solutions. Since the quantum theory, if generally true as a theory of elementary matter, should apply equally to the relativistic region of elementary matter phenomena as to nonrelativistic phenomena, and since this has not been accomplished yet (for reasons that will be discussed in Chapter 2), in the form of a relativistically covariant 'quantum field theory' that would satisfy the requirements of both the quantum theory and the theory of relativity, simultaneously, it must be admitted by the objective scientist that the quantum theory has not yet established itself as a fundamental theory of elementary matter, even though it is an empirically correct description of atomic and elementary particle phenomena under particular experimental circumstances. (Sachs, QM from GR, xi-xii)

The fundamental problems that Sachs has identified have a much deeper origin than he has alluded to at this juncture. He speaks of the philosophical limitations to quantum theory, but the philosophical concepts that are ignored due to the limitations imposed by the quantum are actually based upon sound physical reckoning at an earlier time in scientific development which has now been forgotten and thus relegated to history alone by many modern physicists. As new advances are made in science, concepts evolve beyond their original meaning as well as their original purpose and intent. By evolving in this manner, they may no longer resemble what they were originally and their origins may become lost or rendered unrecognizable.

The problems noted above run much deeper than modern quantum theory alone and reflect our overall concept of the physical world independent of quantum theory. They actually date back to the ancient Greek natural philosophers that first pondered whether physical reality is discrete or continuous. Democritus and the atomists propounded the discrete view of matter as opposed to the Aristotelian concept of the plenum, a continuous form of matter. The earliest records of this dichotomy date still earlier to the mathematical interpretations of physical reality as expressed by the Pythagoreans. The Pythagoreans sought a discrete arithmetical explanation of reality that failed, so the first philosophical development of 'science' yielded to a geometric description of the world that consisted of measuring continuous extensions in space. In this manner, physical measurement became the basis of all science that was to follow.

This fundamental dichotomy in the scientific perspective and attitude seems to be a product of our common human perception of the world. As such, it has continued to evolve with science unabated throughout the historical development of science, although it may have appeared in many different disguises. The modern equivalent to this philosophical and scientific entanglement of fundamental concepts can be found in the debate on whether quantum theory and discrete particles or relativity characterized by continuous field represents the most fundamental scientific view of matter. On the other hand, this debate is also an heir of certain philosophical debates that began during the latter part of the nineteenth century between Ernst Mach, other scientists and scholars. These debates on the true nature of physical reality reflected growing concerns and questions whether scientific theories and laws represented physical reality itself, our perception of reality (whatever it might be) or our mental categorization of portions of that reality. These particular debates laid the very foundations of an emerging new science called psychology. Ironically, Mach argued against the 'atomic' view of matter since humans could not directly perceive so small a unit of matter even while his work on what has become known as 'Mach's principle' became a fundamental pillar upon which general relativity, and thus a new view of matter, was built.

Mach's views that science merely represents economical representations of our perceptions of reality rather than reality itself, a view which later became associated with logical positivism, is the philosophical grandparent of the modern interpretations of quantum theory whereby the Heisenberg uncertainty principle places absolute limits on our knowledge of reality while mathematical models alone, devoid of philosophical and metaphysical content, are valid for modeling quantum mechanics and QED. Undoubtedly, Mach's philosophical and scientific influences represent a very good example of unintended and unwanted consequences. His work influenced both sides of the modern debates over the nature of physical reality. The opposing view is that of 'realism' which is a hallmark of the field theoretic viewpoint of general relativity as well as relativity theory in general, although not limited to relativity theory alone. It is within this context that some scientists came to question whether the high degree of accuracy established by QED renders quantum theory impregnable and free of serious challenge even though they may not be philosophical relativists nor follow a field theoretic approach to reality. These scientists are 'realists' who are bothered, whether they are cognizant of their 'realism' or not, by the lack of 'deeper understandings' in modern quantum theory.

Sachs is one of the few theoretical physicists who has actively sought to explicitly define the problems and flaws besetting modern physics and the quantum theory. In this quest, Sachs has noted two distinct and separate strains of scientific progress within modern physics.

> The compelling point about the *simultaneous* occurrence of these two revolutions (relativity and the quantum) is that when their axiomatic bases are examined *together*, as the basis of a more general theory that could encompass explanations of phenomena that require conditions imposed by both theories of matter (such as current 'high energy physics"), it is found that the widened basis, which is called 'relativistic quantum field theory', is indeed logically inconsistent because there appear, under a single umbrella, assertions that logically exclude each other. (Sachs, 1988, 236-237)

These are just modern versions of the age-old schism between the discrete and continuous expressions of matter or physical reality, the logical and mutually exclusive nature of the quantum (the discrete) and the field (the continuous) that are mentioned above. Sachs does little to hide either this fact or his criticism of the shortcomings and evolutionary direction of present day physics. He has concluded that "neither the quantum theory nor the theory of relativity are in themselves complete as fundamental theories of matter" (Sachs, 256) due to the fact that they represent incompatible fundamental concepts of the discrete and continuous aspects of nature. Therefore, it would seem that Sachs believes that neither the field nor the quantum approach to physical reality, as they have so far been expressed, offers a final solution to the question of the true nature of physical reality.

Sachs has gone still further and tabulated all of the differences between the quantum and relativity worldviews.

> Are the quantum and relativity theories compatible with each other, in terms of their respective fundamental assertions? My answer is: No! A close examination of the irreducible premises of each of these theories reveals that they are indeed incompatible. A long treatise, or possibly a Ph.D. thesis in the Philosophy of Physics, could be written on this subject. I have discussed it in my recent book, **Einstein Versus Bohr** (Open Court Publishing Co., 1988), but there is much more to say on this subject than I have said in my book.
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> Briefly, examples of these incompatibilities from the point of view of logical structure are the following, for 'quantum theory' *versus* 'relativity theory':
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> - A) Principle of complementarity, implying 'pluralism', *versus* principle of relativity, implying 'monism'.
> - B) Atomism, elementarity and seperability of particles of matter and a model in terms of an 'open system', *versus* the continuous field concept and a model in terms of a 'closed system' at the outset, i.e. the basic integrability of material components from a system of matter.
> - C) In our approach to what it is that we truly 'know', we have the conflict of logical positivism *versus* realism--the former asserting that all we can possibly know is what we can verify directly in measurements; the latter asserting that there is a real world, independent of whatever we do to find out about it, and that indeed we may learn things about the world that are not directly verifiable in measurements, though they are inferable from the logical structure of our theories, if they also predict correct empirical facts.
> - D) Irreducible subjectivity in the role of measuring apparatus as a fundamental ingredient in our understanding of matter *versus* full objectivity, in which the

> 'subject' and the 'object' of an interacting system are truly interchangeable without losing the objective truth of the entire closed system.
>
> - E) Indeterminism (all variables of matter are not 'predetermined') *versus* determinism (all variables of matter are predetermined).
> - F) Linear mathematics *versus* nonlinear mathematics.
> - G) A fundamental role in the laws of nature of probabilities and their calculus, *versus* the role of probabilities only as a tool for the observer, but playing no fundamental role in the laws of nature.
> - H) Special reference frame of the measuring apparatus *versus* no special frame of reference for any component of a closed system, whether or not one of these components is a large macroobserver and another a small bit of micromatter. (Sachs, Internet)

He is not alone among scientists and scholars in recognizing the particular differences between the two worldviews, although he is probably the only scientist to so carefully tabulate the fundamental differences. Although this particular list appears on Sachs' web page on the Internet, it does not appear on the Internet alone. Sachs previously published similar lists in his books *Einstein versus Bohr: The Continuing Controversies in Physics* (Sachs, 1988, 238) and *Quantum Mechanics from General Relativity: An Approximation for a Theory of Inertia* (Sachs, 1986, 8) while many of his basic arguments are also expressed and supported in the later publication *Dialogues on Modern Physics*. (Sachs, 1998)

Many of these differences are not recent discoveries by Sachs as might be implied above. Even the founders and early defenders of quantum theory, as well as their students, have noted some of the same problems. In the case of QED, Julian Schwinger, one of the founders of quantum electrodynamics who shared a Nobel Prize for his work, summed up his view on the situation in 1956.

> It seems that we have reached the limits of the quantum theory of measurement, which asserts the possibility of instantaneous observations, without reference to specific agencies. The localization of charge with indefinite precision requires for its realization a coupling with the electromagnetic field that can attain arbitrarily large magnitudes. The resulting appearance of divergences, and contradictions, serves to deny the basic measurement hypothesis. We conclude that a convergent theory cannot be formulated consistently within the framework of present space-time concepts. To limit the magnitude of interactions while retaining the customary coordinate description is contradictory, since no mechanism is provided for precisely localized measurements. (Schwinger, xvii)

Schwinger clearly acknowledged that QED, the original 'quantum field theory,' had reached a specific limit whereby it could not be judged without reference to an outside framework of space-time. This fact would seem to exemplify Gödel's theorem, whereby the truth or validity of any logical system cannot be determined from within that system. So any logical system's validity and consistency can only be established from within a larger and more comprehensive framework or system. The common interpretation of quantum mechanics denies anything beyond itself so its validity and consistency cannot be established either philosophically or physically. The prevalent framework of space-time, referred to as the "customary coordinate description" by Schwinger, was then and is presently supplied by the theories of relativity. Schwinger obviously believed that QED had not yet been unified with special relativity and grave problems existed between the two fields of physics. Special relativity was merely used as a limiting condition for the mathematical model of quantum field theory. QED was not the expected and hoped for unification of relativity and the quantum. It would further seem that any real unification to which scientists might subscribe would be between quantum mechanics and GR by necessity, since both describe the motion of matter in space-time. Such a unification with GR would certainly include a unification with special relativity, rather than the reverse.

A similar notion was expressed by Victor Guillemin, a student of Arnold Sommerfeld who was an early contributor to quantum theory before the discovery of quantum mechanics.

> The ambitious program of explaining all properties of particles and all of their interactions in terms of fields has actually been successful only for three of them: the photons, electrons and positrons. This limited quantum field theory has the special name of *quantum electrodynamics*. It results from a union of classical electrodynamics and quantum theory, modified to be compatible with the principles of relativity. (Guillemin, 176)

As Guillemin testified in his history of quantum theory, QED is only "compatible" with the principles of relativity. Sachs would not even go this far and instead denies the compatibility of quantum mechanics and special relativity. QED has not provided a framework for the complete unification of special relativity and the quantum, let alone GR and the quantum, despite four decades of intensive efforts in that direction. Sachs claims that there has "been no real success in unifying the quantum theory and the theory of relativity, since the discovery of quantum mechanics in the 1920s" because "of the fundamental incompatibilities, discussed above. To fully unify these two theories is like trying to force a square peg into a round hole!" Nor is it possible to "re-express the quantum theory with the relativity requirements fully removed"

> This is because the basic elements of the quantum theory, according to the underpinnings of the Copenhagen school, are the unbreakable triads of the measurement process: emitter-signal-absorber. The problem is the following: While the emitter and absorber components of this unbreakable triad have a non-relativistic limit in their description, i.e. one can always find a reference frame that is at rest with respect to them, from which we describe them mathematically, the signal component does not have such a limit. This is well known in the case of electrodynamic interaction, where the signal is a photon. But even in other types of interaction, such as the nuclear interaction, one must still be able to describe the signal (the pions, etc.) relativistically because of their fundamental high energy interaction with other matter. It then follows that the 'emitter-signal-absorber' units of measurement, according to the quantum theory itself, must necessarily be described fully in terms of the quantum theory subject to the symmetry requirements of relativity theory. (Sachs, 1996, Internet)

If Sachs' opinion is correct, and he argues his case quite thoroughly and convincingly, special relativity and quantum mechanics have not yet been unified, are diametrically opposed to each other and yet quantum mechanics cannot exist in a complete form independent of special relativity. While these facts and restrictions pose a serious dilemma for physics in its present state (as well as its future progress toward unification), which cannot be easily overcome, they need not prove an impossibility for physics to overcome.

Sachs suggests that quantum theory not be used as the basis of unification under these circumstances. Unification must proceed from relativity theory in the form of GR to the quantum rather than the reverse.

> An obvious alternative approach that might get us out of this dilemma is the following: Start at the outset with a theory that is based fully on the premises and the ensuing mathematical expression of the theory of general relativity (i.e. curved space-time, field concept, determinism, closed system, etc. - implying a nonlocal, nonlinear field theory), yet a theory in which a part of the generally covariant formalism reduces to the formal probability calculus of quantum mechanics, as a linear approximation for a nonlinear, nonlocal field theory of matter. (Sachs, 1997, Internet)

Although Bohm would not have started directly from GR, as suggested by Sachs, he did come to nearly the same conclusion that the QFTs, as they stood, did not offer an adequate basis for the pursuit of unification.

> ... David Bohm criticizes the current effort of quantum theorists to achieve a grand unification theory because he believes the pursuit of the ultimate particle, the ultimate quantum, or the ultimate force makes a fundamental error - it assumes that the universe is made up of parts. By pursuing nature as if she were made of parts, scientists have found parts. Bohm thinks, however, that no ultimate or "grandfather" part will be discovered, only more and more parts-parts which will keep elusively dissolving into themselves. (Briggs and Peat, 78)

For his own part, Bohm's concepts of an ultimate physical reality slowly migrated from the concept of 'hidden variables' to that of an underlying 'quantum potential field.' The notion of 'wholeness' is basic to Bohm's final concept of reality, which is to say that he settled on continuity and connectivity as the most fundamental aspects of reality, rather than the discrete.

While Sachs certainly makes a case for the fundamental differences between relativity and the quantum, other problems have long been known to exist. In QED, each particle is associated with a field, so there are as many fields as there are different particles. This situation gives rise to an unpleasant expansion of the concept of field which some have criticized. (Popper, 194) In this manner, the concept of a single continuous field representing either all of physical reality or the space-time continuum alone has been reduced to an infinite number of discrete fields which are not continuous within a single whole. Continuity itself has been subjugated by the quantum under the guise of QED and has thus been destroyed by the discrete giving rise to the unpleasant feeling of dissatisfaction experienced by some scientists. Yet far more serious problems exist for QED. At the point where the different fields interact, one would expect to find the action and reaction of the particles as caused by forces in the classical sense of the term. However, at those points mathematical divergences occur which render the masses of elementary particles infinite and undefined. Using perturbation methods these divergences (or infinities) can be renormalized to yield finite and thus measurable answers. Therefore, localizing and defining a point particle in QED amounts to using an artificial mathematical method for no other physically valid reason than that the method yields finite results that can be experimentally verified. This method introduces a conceptual catastrophe into the QED model.

The artificial nature of renormalization is at the very least philosophically unsatisfying as well as unsettling to many scientists and scholars. The process of renormalization was at the bottom of Schwinger's dissatisfaction with QED and represents one of the major problems as sensed by other scientists. The method is clearly *ad hoc,* but otherwise a necessary evil to render QED a workable physical model, which is all that QED can claim to be without a conceptual basis. Rendering QED a workable model does not make it a complete and consistent theory. Karl Popper was very critical of this shortcoming of QED.

> Moreover, the situation is unsatisfactory even within electrodynamics, is spite of its predictive successes. For the theory, as it stands, is not a deductive system. It is, rather, something between a deductive system and a collection of calculating procedures of somewhat *ad hoc* character. I have in mind, especially, the so-called *'method of renormalizatio*n': at present, it involves the replacement of an expression of the form 'lim *log x - lim log y*' by the expression 'lim (*log x - log y*)'; a replacement for which no better justification is offered than that the former expression turns out to be equal to - and therefore to be indeterminate, while the latter expression leads to excellent results (especially in the calculation of the so-called Lamb-Retherford shift). It should be possible, I think, either to find a theoretical justification for the replacement or else to replace the physical idea of renormalization by another physical idea - one that allows us to avoid these indeterminate expressions. (Popper, 194-195).

While Popper's criticism was leveled several decades ago, shortly after QED was first developed, it is still a valid criticism. Popper's statement can be readily compared to a similar and far more recent criticism by Bohm.

> Here, we may hope to get sonic clues by considering problems in a domain where current theories do not yield generally satisfactory results, i.e. one connected with very high energies and very short distances. With regard to such problems, we first note that the present relativistic quantum field theory meets severe difficulties which raise serious doubts as to its internal self-consistency. There are the difficulties arising in connection with the divergences (infinite results) obtained in calculations of the effects of interactions of various kinds of particles and fields. It is true that for the special case of electromagnetic interactions such divergences can be avoided to a certain extent by means of the so-called 'renormalization' techniques. It is by no means clear, however, that these techniques can be placed on a secure logical mathematical basis.' Moreover, for the problem of mesonic and other interactions, the renormalization method does not work well even when considered as a purely technical manipulation of mathematical symbols, apart from the question of its logical justification. While it has not been proved conclusively, as yet, that the infinities described above are essential characteristics of the theory, there is already a considerable amount of evidence in favour of such a conclusion.
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> It is generally agreed that, if as seems rather likely, the theory does not converge, then some fundamental change must be made in its treatment of interactions involving very short distances, from which domain all the difficulties arise (as one sees in a detailed mathematical analysis).
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> Most of the proponents of the usual interpretation of the quantum theory would not deny that such a fundamental change seems to be needed in the present theory. Indeed, some of the,. including Heisenberg are even ready to go so far as to give up completely our notions of a definable space and time, in connection with such very short distances, while comparably fundamental changes in other principles, such as those of relativity, have also been considered by a number of physicists (in connection with the theory of non-local fields). But there seems to exist a widespread impression that the principles of quantum mechanics almost certainly will not have to be changed in essence. In other

> words, it is felt that however radical the changes in physical theories may be they will only build upon the principles of the present quantum theory as a foundation, and perhaps enrich and generalize these principles by supplying them with a newer and broader scope of application.
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> I have never been able to discover any well-founded reasons as to why there exists so high a degree of confidence in the general principles of the current form of the quantum theory. Several physicists have suggested that the trend of the century is away from determinism, and that a step backwards is not very likely. This, however, is a speculation of a kind that could easily be made in any period concerning theories that have hitherto been successful. (For example, classical physicists of the nineteenth century could have argued with equal justification that the trend of the times was toward *more* determinism, whereas future events would have proved this speculation wrong. Still others have adduced a psychological preference for indeterministic theories, but this may well be just a result of their having become accustomed to such theories. Classical physicists of the nineteenth century would surely have expressed an equally powerful psychological bias toward determinism.) (Bohm, 83-84)

QED is considered theoretically inconsistent because of renormalization and other problems in spite of its great successes. Arguments to the contrary, based upon the fact that advances have been made in QED and quantum theory since Schwinger and Popper first voiced their opinions, do not 'hold water' since Bohm makes essentially the same criticisms three decades later.

Bohm and J.-P. Vigier developed the concept of 'hidden variables' in the early 1950s. Their purpose was to answer the criticisms against quantum mechanics that had been leveled more than two decades earlier by Albert Einstein, Boris Podolsky and Nathan Rosen. The consequences and later philosophical development of the issues raised by the EPR paradox form one of the three major trends or conceptual themes that now undermine the credibility or the quantum worldview, although some would say that the lack of a quantum based metaphysics better describes the situation. They form the basis of nearly all the arguments against the completeness and consistency of the quantum theory in its many modern renditions. The other conceptual factors are the continuing development of QFTs based upon the model of QED and the rise in the fortunes, successes and popularity of GR since the 1960s. GR has become so successful in the past two decades that measured values associated with astronomical phenomena and events match predicted values to such a high degree that GR now rivals or surpasses the precision of QED. This fact places the claim that QED is the most accurate theory ever proposed in grave jeopardy and therefore challenges the status of QFTs as the basis for unification of all the laws of physics.

Bohm's concept of 'hidden variables' has been both a boon and a bane for modern physics: A boon because it has fostered new areas of inquiry in physics and a bane for its mere existence as an argument against other interpretations of the Heisenberg uncertainty principle. Many scientists could easily deny the possibility of 'hidden variables' based upon von Neumann's 1932 theorem that they could not exist, but any such arguments are seriously flawed. A mathematical proof, such as von Neumann's, does not affect physical reality in any manner. Mathematics provides models for physical theories and thus possibilities, not real situations. Just because a situation is possible (or even impossible) in mathematics does not guarantee that the situation exists (or not) in nature. Nothing can be proved or disproved with absolute certainty in nature. According to Gödel's theorem, any mathematical theorem is limited by its basic assumptions and axioms. 'If' nature is a truly mathematical system, then absolute truth in nature could only be determined if all of the axioms and fundamental principles in nature were identified. Learning and enumerating all of the basic axioms of nature, if even possible, would constitute the discovery of a final and complete 'theory of everything,' a TOE. Even then the TOE could never be proved or disproved as absolutely true, because you would have to go beyond the TOE to a larger logical system to prove it. If the TOE represented everything in nature, then it would be impossible to go beyond it to prove it. So, it is philosophically impossible to disprove the existence of 'hidden variables' and von Neumann's theorem is useless in this regard. Nature, not mathematics, is the final arbiter of each and every physical theory.

On the other hand, Bohm's early work lead to the work of John S. Bell. Bell showed that specific mathematical relationships would result between the spin measurements of different particles with connected or joint probabilities. These relationships were called 'Bell inequalities.' According to the quantum theory, these relationships could be violated, but only in a prescribed manner, thus opening the possibility for experimentally testing the consequences of the quantum theory. Bell's theorem neither proved nor disproved anything in nature, but suggested a course of action for scientists and the probable outcome of an experiment given specific physical conditions. Bell's theorem and its application thus reflect the true relationship between mathematics, physics and nature. Alain Aspect and his colleagues conducted such experiments in 1981 with surprising results. Particles that interacted quantum mechanically and then separated were found to have maintained some form of non-local contact when their spins were later determined. It has been assumed that the particles communicated information in some unknown and unsuspected manner that violated the rules of special relativity. It has further been assumed that these results confirmed quantum mechanics at the expense of relativity theory.

Under these circumstances, one would think that Aspect's results would have shaken the very foundations of physics and possibly acted as a 'crucial experiment' in the downfall of the relativistic worldview, but this has not occurred. The reaction of physicists and scholars was quite mixed. Peter Davies relates a story on how various members of the physics community reacted to the results of Aspect's experiment.

> Several months after Aspect published the results of his experiment I had the privilege of making a BBC radio documentary programme about the conceptual paradoxes of quantum physics. The contributors included Aspect himself, John Bell, David Bohm, John Wheeler, John Taylor, and Sir Rudolph Peierls. I asked all of them what they made of Aspect's results and whether they thought that commonsense reality was now dead. The variety of answers was astonishing.
>
> One or two of the contributors felt no surprise. Their faith in the official view of the quantum theory as enunciated long ago by Bohr was so strong that they felt the Aspect experiment merely provided confirmation (albeit welcome confirmation) of what was never seriously in doubt. On the other hand, some were not prepared to leave it at that. Their belief in commonsense reality - the objective reality sought by Einstein - remained unshaken. What would have to go, they argued, was the assumption that signals could not travel faster than light. There must be some 'ghostly action at a distance' after all. Bohm

already has a ready-made theory that incorporates such 'non-local' effects.

And what of the time-signalling paradoxes? Well, perhaps something prevents such signals being sent in a controlled way? The issue was left vague.

Although not all physicists seem to accept the overthrow of naive reality, Bohr's position remains the official view, and has undoubtedly been strengthened by Aspect's results. If this position is adopted it has some very profound implications for the nature of the physical world.

First, the two-particle arrangement described in the foregoing reveals that the reality of a particle 'over there' is indissolubly linked with the reality of a particle 'over here'. The simplistic assumption that lust because two particles have moved a long way apart we can consider them as separate and independent physical entities is badly wrong. Unless separate measurements have taken place on both the particles, they remain part of a unified whole. What we mean by reality is defined only by the total experimental arrangement, which could be spread out over a large region. Furthermore, although in the Aspect experiment such a two-particle 'holistic' system is deliberately set up in a controlled way, all the time particles are continually interacting and separating as a result of their natural activity. The non-local aspect of quantum systems is therefore a general property of nature, and not just a freak situation manufactured in the laboratory.

Some people have emphasised that quantum physics implies a world in which individual particles of matter do not realty exist in their own right as primary entities. Instead, only the collection of all particles treated as a whole, including those that go to make up the measuring apparatus, has the status of 'reality'.

The more traditional view of reality based on classical Newtonian physics is quite different. According to Newtonian philosophy, matter is made up of particles, but the particles are regarded simply as building blocks that can assemble into larger units. This picture is appealing because we can easily visualize myriads of these elementary particles like solid balls, locked together to form a familiar object such as a rock. All the properties possessed of the rock can then be attributed to the atoms, or whatever basic building block is fashionable. The rock is *made up of* elementary particles and the particles are simply fragments of the rock. Nothing more. The German physicist Otto Frisch, the discoverer of nuclear fission, describes the classical picture as follows:

> 'It takes the line that there is definitely an outside world consisting of particles which have location, size, hardness and soon. It is a little more doubtful whether they have colour and smell; still, they are *bonafide* panicles which exist there whether or not we observe them.'

We might call this classical philosophy 'naive realism'.

In quantum physics this simplistic classical relationship between the whole and its parts is totally inadequate. The quantum factor forces us to perceive particles only in relation to the whole. In this respect it is wrong to regard the elementary particles of matter as things that collectively assemble to form bigger things. Instead, the world is more accurately described as a network of *relations.*

To the naive realist the universe is a collection of objects. To the quantum physicist it is an inseparable web of vibrating energy patterns in which no one component has reality independently of the entirety; and included in the entirety is the observer.

The American physicist H. P. Stapp has expressed the quantum concept of particle in these words:

> 'An elementary particle is not an independently existing unanalysable entity. It is, m essence, a set of relationships that reach outward to other things.'

One is reminded of the words of William Blake: 'To see a world in a grain of sand . . .' We must envisage all matter and energy everywhere encompassed in a unified existence. (Davies, 1984, 47-49)

Davies' description clearly illustrates that Aspect's experiment did not seriously alter anyone's prior commitment to his or her own versions of physical reality. It only demonstrated that there is far more to physical reality than is presently known and until we know more of the nature of reality we cannot make any final decisions regarding the superiority of individual theories, which at first glance seem mutually contradictory.

Perhaps Aspects' results were not as revolutionary as they might have seemed because they did not directly attack the problems addressed by EPR. Einstein's original argument in EPR concerned relative space and time. In essence, it was implied that any two particles could theoretically be used to establish a space-time framework independent of the possibility that could have interacted together in the past. This is the simplest possible statement of relativity. The mere existence of two particles determines a relative space-time framework. This notion is related to Mach's argument, better known as Mach's principle, that if only one material particle existed in the whole universe, its motion could not be distinguished, so space must be relative rather than absolute. In a similar manner, EPR implied that this simple notion of relativity would not be valid if the prevalent interpretation of quantum mechanics were true because two independent particles could not exist beyond their initial interaction. It was at this point that 'hidden variables' entered the picture. If the two particles did exist both prior to and after their interaction, the EPR argument also implied that the Heisenberg uncertainty principle did not take into consideration all of the factors that could possibly determine a relative space-time framework. Thus, there must be 'hidden variables' which scientists had not yet taken in account in their theories. The Heisenberg uncertainty principle denies the existence of simple relativity by denying the ultimate reality of material particles that alone can determine the relative space-time framework in which they can physically interact. The Aspect experiment measured and compared spins, not the positions in space and time that are necessary to establish a relative space-time framework. So Aspect's experiment only partially answered the questions that it was designed to solve.

Relative spins do not determine a space-time framework. However, it is assumed that a space-time framework is necessary for spins to exist and be measured. Therefore, Aspect's experiment demonstrated a sufficient condition, but not a necessary argument, against relativity in favor of quantum mechanics. Aspect's results do not necessitate an abandonment of either special relativity or the fundamental relativistic perspective of the continuous field. The problem is that no one has yet demonstrated what a 'spin' really is other than to state that it is a fundamental property of elementary particles. So, no one really knows how 'spin' is related to the relative space-time framework established by the existence of the particles demonstrating 'spin.' In other words, more experiments that are substantially different in design must be developed and conducted to substantiate the implications of Aspect's experimental results before questions regarding space-time and the quantum can be fully and completely answered. This explanation would account for the mixed reviews of Aspect's experiment demonstrated by the participants in Davies' gathering. After all has been considered, there is no reason to believe that the concept of 'hidden variables' is dead although the concept is no longer popular, just as there is no evidence that quantum mechanics is 'better' or more fundamental than relativity theory. No single approach has yet lead to a successful unification in physics. So quantum mechanics, in either its older or newer incarnations (QED and other QFTs), holds no priority over other fundamental theories in physics.

In the meantime, Bohm's physics has gained many adherents and has grown popular and respectable from its original basis in 'hidden variables.' Indeed, Bohm's fortunes have been increasing apace with the growth and the expansion of quantum theory which seems to imply that more scientists have been looking for alternatives to the standard views of quantum theory even as quantum theory becomes more successful in explaining a wider range of phenomena. Other scientists do not like Bohm's physics, but still admit that there is merit to his criticisms. Far more scientists would agree that Bohm's criticisms of quantum theory are the same as their own misgivings even though their approach and solutions to the dilemma differ radically from Bohm's.

In 1961 a small symposium was held under the auspices of the BBC Third Programme. The main purpose of the program was to explain what 'electrons were really like' in layman's terms. But the program turned into a review and debate over Bohm's philosophical and physical views on the quantum problem. The participants in the program either sided with or against Bohm's scientific 'heresies.'

> Most of Bohm's professional colleagues have been deaf to this call for a fundamental change of strategy. Some, like Professor Maurice Pryce (who debates the issue with Bohm in Chapter 4 below), have condemned Bohm's proposals as positively misguided and misleading. And, since Bohm's challenge questions the standing of quantum mechanics as a whole, the resulting debate has branched far and wide. It has not only provoked a reappraisal of the intellectual foundations on which the orthodox interpretations of quantum mechanics are based-which are lucidly explained by Professor A. B. Pippard and Professor N. Kemmer in Chapters r and 2-it has also precipitated arguments about historical precedents, logical proprieties and philosophical methods. So it is fitting and necessary that, in the present book, two authorities on the history and logic of science (Dr Mary B. Hesse and Professor N. R. Hanson) should enter the ring along with the theoretical physicists. (Toulmin, 10)

In this case, the physicists argued against Bohm's views while the non-physicists argued for Bohm's views. Bohm claimed in general that "theoretical speculation about sub-quantum physics is - for all that von Neumann may have proved - both legitimate and necessary." (Toulmin, 17) This stratagem clearly indicated that Bohm did not accept the 'mathematical' proof that 'hidden variables' were excluded by nature from consideration. Although he did not condone Bohm's opinions, even Professor Pryce objected to the QED process of renormalization.

> Recently, successes have been fewer; breaks in the ranks have appeared. As Professor Pryce remarked, the most serious of these arise when 'infinite results come out of the mathematics'.
>
> The sort of thing he had in mind was this: when the theory's wave equations are applied to the scattering of particles of very high energy, those equations literally fall apart. The integrals of which they are made diverge. The result is an infinitude of solutions for each equation, rather than the small, tractable set of solutions which usually results at low energies. Now, equations equally well satisfied by any one of an infinity of values hardly constitute an intelligible physics at all; they are compatible with almost any experimental state of affairs whatever. Excluding nothing, they say nothing, describe

> nothing, predict nothing. Faced with this problem, theoreticians like Bethe, Tomanaga and Schwinger invented a technique to diminish the number of possible solutions into something which practising physicists could manage. The result is a rather arbitrary procedure called 'renormalization'. It rejects as physically unpromising most solutions of any wave equation. But it does this in a manner mathematically objectionable, physically arbitrary and aesthetically inelegant. Of course, if renormalization were *wholly* successful these shortcomings could be tolerated as easily as were the conceptual novelties of the last generation.
>
> But this is not the case. When he is absorbed in high-energy problems the scientist must renormalize his equations in order to continue with his physics at all, but the consequences may be more costly than the gain. Before renormalization, he assumed, let us say, that a certain volume of space contained a number of particles, and the physical problem was to discover the probabilities that these particles would have certain positions, velocities or densities. But the mathematical form in which he describes his experiment is altered by renormalization, and altered in such a way that he can no longer assume that there really are any actual particles within the volume he is considering . . . since the equations are applicable either way, particle or not. The physicist's probability determinations then become shadowy references to the 'ghost states of particles', the references themselves are called 'negative probabilities'; and it is difficult to attach any real physical sense to these expressions. This all looks highly unpromising as physical theory.
>
> Now, the objections raised thirty years ago, when physics was forced on to unfamiliar conceptual tracks, have again been heard through the land. The successes of quantum theory, which formerly had silenced criticisms, are no longer so obvious. Indeed, the very mathematical structure of the theory seems unsound after its failure with problems involving high-energy particles. (Hanson, 87-89)

The references to renormalization as "mathematically objectionable, physically arbitrary and aesthetically inelegant" certainly do not seem an endorsement of the practice. Unless a theoretical reason is found to explain why renormalization is required, it will continue to be suspect. The practice of renormalization will continue to cause some amount of distress and controversy even though QED remains a valid and important theory. The need to complete the QED theory is demanded by the very success of QED, but the tides of progress in physics have moved beyond such questions to other shores and no one seems interested in solving QED's inherent problems.

Another meeting in which Bohm was both an organizer and a participant was held in 1968. The purpose of the colloquium was to locate the "unrest (at the foundational level of quantum theory) unambiguously, or failing that, at least to have the various arguments that locate the source of the trouble in different places presented alongside one another." (Bastin,1) The "unrest" that Bastin and the other participants had experienced was actually easy to identify.

> The main-stream view is not satisfactory to the logician, because it draws elements from several incompatible sources which the common sense and experience of the working physicist alone succeed in combining into an effective way of working. First among these sources is the detailed success of the schematization which quantum theory had produced by 1928 of the low energy spectra and therefore of atomic energy levels. With this schematization there was a method of calculating which worked and whose success could never be gone back on. However a difficulty now arose because of a fundamental change in outlook which the quantum theory made necessary. The new schemata required for their use that one cease to demand answers to questions which

> classical physics had regarded as essential to its very way of thinking that it should be able to answer. On the other hand no way of presenting the new schemata - not even the radically phenomenological method due to Heisenberg of operating with what was known about a quantum structure in matrix form - could stand on its own without drawing on thinking that was an integral part of the classical picture.
>
> A *prima facie* circularity thus needs to be recognized in the dependence of quantum theory upon classical concepts. Quantum theory took its origins in an attempt to remedy a fundamental flaw in the classical physics (a flaw which could no longer be ignored once the 'ultra-violet catastrophe[3]in the theory of the spectral energy distribution had become fully apparent). Through its success in this original situation quantum theory came to be thought capable of subsuming classical theory as a special case, and capable, too, of applying its new and more profound concepts to make comprehensible a class of phenomena which were necessarily incomprehensible in the older picture. However, this expectation on behalf of the quantum theory is combined with the requirement that every quantum concept be operationally specified using classical arrangements of apparatus (and therefore-surely-of classical concepts) and therein lies the circularity. (Bastin, 1-2)

Circular arguments are disliked in both physics and philosophy. In physics, circularity goes against the grain of searching for the most fundamental principles of nature, the goal of physics. They indicate either a logical flaw or an unwanted limitation in the basic concepts upon which the logical structure of science is based. The same is true of philosophy. However, in purely philosophical cases the basic axioms upon which the logical structure is built are products of the human mind while nature determines the fundamental principles and humans interpret them in science.

Logical consistency is thus an important feature in both philosophy and science and the detected circularity in quantum theory denies the physics of the quantum the logical consistency that it needs. The question facing physicists is how important is logical consistency to them when faced with a theory, such as quantum theory, which is practically and experimentally valid. Is logical consistency a valid criterion for questioning a theory when it is otherwise successful?

> We now have the main strands that make up main-stream quantum theory. Each has its thorough-going adherents who want to achieve logical consistency at all costs in the terms of the strand of their particular choice and see all the other strands as convenient partial expressions or aspects of the correct picture whose validity extends just so far as each can be presented in the terms of their chosen strand. No such single strand has achieved a picture of the quantum situation which satisfies an overwhelming majority of physicists (and the 'Quantum Theory and Beyond' colloquium did riot alter this negative state of affairs). One is therefore forced to eon template a situation which must be unique in the history of science where the practitioners of a scientific theory which has reached the stage of being regarded as a finished product habitually work with a jumble of elements taken from a variety of different conceptual frameworks none of which, singly, is adequate to present the facts that are known, and each of which is partly or even largely incompatible with the rest. What keeps these practitioners feeling that it is one discipline they are operating is quite a puzzle. Partly it is a faith in the existence of a growing body of knowledge which constitutes physics and which persists massively unchanged whatever we may add onto it in the way of revolutionary principles or discoveries. Partly again it is the persistence of classical methods and concepts which have a degree of success which it is difficult to account for if the changes demanded by quantum theory are taken literally. (Bastin, 8-9)

To Bastin and the other colloquium participants, the diverse body of knowledge that science terms 'quantum theory' is thus a logical "muddle."

> However one feels bound to protest that there is something very odd about renouncing the hope of understanding something and yet claiming to know that it is that something and nothing else to which experiment leads us. To put the point more sharply, no amount of experimental evidence can count in favour of a logical muddle. (Bastin, 8)

Nature, in essence, would never present science with a logical muddle. Either human misunderstanding or the lack of a complete understanding can result in a muddle. Bastin is not the first to use this term to describe our present understanding of reality from the quantum perspective, nor will he be the last.

All of the experience of science indicates that nature, or rather physical reality, is logical and can be modeled using mathematics, a branch of logic itself. Scientists and scholars assume that nature is logical in every possible circumstance and that we can therefore know nature by finding the simplest and most fundamental axioms and principles upon which nature is based. If quantum theory presents a logical muddle, then either our axioms are wrong or incomplete, such that they are not fundamental enough. If this is true, then a new fundamental paradigm should be found to describe nature. On the other hand, there is no absolute guarantee that the quantum theory or some form of the quantum concept would remain as the basis of a new fundamental paradigm although it would, by necessity, be required that any new theory account for the quantum theory as it is presently understood.

> The unprecedented situation in quantum theory foundations may he held to be so extreme as to require the search for new paradigms, as it were from cold. Some of the contributors to 'Quantum Theory and Beyond,' do hold just this, and have been prepared to stick their necks out in putting forward models which depart radically from quantum theory as it is usually known.
>
> A little more needs to be said in explanation of this neck-sticking-out. Not long ago such efforts were met with complete incredulity on the part of physicists who were competent to evaluate such attempts. Current philosophy of science presupposed that distinct but comparable theories on fundamental issues could exist for empirical adjudication, and that such adjudication was the scientific norm, while in physical practice the edifice of physics was utterly monolithic, any significant conceptual change being always too radical in its effects for the imagination to be able to cope with the intermediate stage of conceptual confusion that it would produce.
>
> Recently there has been widespread recognition that basic changes in physics may be necessary, and the incredulity has changed to scepticism, or perhaps to a feeling of powerlessness. The aim of 'Quantum Theory and Beyond' will have been completely achieved if the scepticism could be changed again to an atmosphere of reasoned assessment of the difficulties and obscurities that have to be overcome before any change in the basic structure of physical theory cart take place. The desired new atmosphere certainly requires that as a first stage, theories significantly different in their basic structure should be seriously discussed. At this first stage they need not be so successful as to be evidently correct. The conceptual muddle in the foundations of quantum theory is serious enough to make this first stage by itself well worth achieving.
>
> The original shock to physicists produced by the quantum theory was that by the introduction of discrete structures into essentially continuous dynamics, advances which could not be ignored were made possible. The step was felt to be unscientific because scientific explanation demanded the possibility of indefinite refinement in the

> measurement of physical quantities, and this possibility, postulates of discreteness must necessarily restrict at some point. In other words a limit of any sort to measurement was felt itself to require explanation in a way that the absence of such limits does not: there is an asymmetry as regards the possibility of explanatory achievement between discrete and continuum theory. (Bastin, 9-10)

It is not as if this muddle, unrest, or whatever scholars wish to call it, has happened upon the scene unexpectedly. Fundamental problems with the quantum perspective have been known, discussed and debated for several decades, but have only been adopted by mainstream science rather late in the game.

All of this rationalization leads back to the basic dichotomy between the discrete and continuous perceptions of reality and again raises the question whether these human perceptions are just that, perceptions alone, or whether they reflect the actual state of physical reality. In either case, if the fundamental concepts and principles of quantum theory are either wrong or incomplete, then a new paradigm for the microstructure of physical reality is needed.

> This preoccupation with finitism can be traced back to a general agreement that there is something seriously wrong with the combination of quantum theory and continuity. This agreement in its turn depended on two or three major positions which emerged from papers and discussions, rather as a 'sense of the meeting'. First: the Bohr, or Copenhagen, interpretation, whether it is correct or not, is certainly insufficient, There has got to be considerable development beyond Bohr, as well as some reconsideration of assumptions. Secondly: it is unlikely that there can be a unitary theory of physics which lays down the whole detail of nature, and there is no clearly marked line for future development that would lead to one complete theory. This conclusion may be held to follow from Bohr's view - and certainly for Bohr completeness would be a false ideal - but it seems in any case that quantum theory has roots in quite different soil from those of say, relativity. Thirdly: the massive coherence and invulnerability to change of ways of thinking and speaking which characterizes classical dynamics, was subjected to critical examination and reconsideration, but the importance which Bohr attached to it was not disputed. (Bastin, 10-11)

No matter how the problem is rationalized, all roads seem to lead back to the fundamental difference between the quantum and relativity, as illustrated by Sachs and others.

The participants in the colloquium were not of a single mind in their approach to such problems, although they all seemed to acknowledge the same basic problems with the quantum theory. It is presently assumed by those who fully accept quantum theory, yet recognize its shortcomings, that quantum theory will eventually solve its own problems without recourse to other ideas. At the very least, these scientists feel that the limits on either nature or our knowledge of nature presented by the quantum concept will remain the basis of any and all new and future paradigms in physics.

> A position favoured quite widely in the colloquium was to accept the thesis that classical ways of thinking are indeed needed at every point to interpret quantum-theoretical formalism, and yet hold that a full understanding of the quantum theory should or could provide us with a fuller and essentially more correct set of concepts for describing the physical world. The classical language - on this view - is not immutable but is subject to alteration, refinement and development.

> Expressing one extreme case of this view in his paper, Kilmister suggests that quantum theory may amount to little more than the imposition of a set of combinatorial conditions upon the energy-values in an essentially classical picture, and that its claim to be a new system of mechanics in its own right is overstated if not actually misleading. (Bastin, 91)

Mainstream quantum theorists have been acting under this assumption for decades. While they have made phenomenal advances, every advance they make raises new problems as the older problems evolve newer identities.

At the other extreme came Bohm's theoretical work. While others thought that the quantum was complete, even though it had not been fully elaborated, Bohm thought the quantum itself meant something different than was normally thought. C.F. Von Weizsäcker correctly interpreted Bohm's viewpoint, but had to be corrected on the significance of Bohm's perspective.

> (VON WEIZSÄCKER): I wonder if I could put Bohm's view like this: In general we start out with a space-time structure to which we add quantum theory, and we describe objects by relying on the theory to tell us what is going on in terms of the space-time structure. Moreover, you say that the way in which we generally look at space-time structure may be too narrow and that quantum theory itself teaches us about an order which is somehow connected with what we originally knew as space-time structure, but which is richer.
>
> (BOHM): Yes.
>
> (VON WEIZSÄCKER): So far, I think, I follow you. On the other hand one might say that since we are here learning something about space-time structure from quantum theory, there is no reason why we should not deduce the whole of what we call space-time structure from quantum theory.
>
> (BOHM): I must object to that. What does the expression 'quantum theory' mean? It represents a certain union of formal and hi-formal language. We are discussing the formal language of quantum theory, more or less as Aharonov says in his paper, using it as a clue to change the ordering of the informal language. (Bastin, 129)

Bohm defended the position that there exists an underlying reality that the quantum theory cannot access or address. Yet the quantum theory does indicate something about this underlying structure of space-time.

Since its very inception, scientists have misinterpreted the Heisenberg uncertainty principle and this has caused a serious rupture between quantum theory and relativity. Quantum theory and special relativity evolved from the same set of problems that was forced upon the world of physics when electric and magnetic phenomena were finally unified into a single theory. They both came as answers to the problems between the interaction of electromagnetic waves and matter where the motion of matter is either governed or represented (according to one's philosophical beliefs) by Newtonian mechanics. Special relativity solved the problems raised by the unification of electricity and magnetism by unifying space and time into a single interdependent framework, but quantum theory dealt with the realm of the very small where space and time are actually welded together. Since the space-time framework is decided by the relative positions of the minutest material particles, any physical theory that deals with that realm would necessarily model the most fundamental interactions of space and time themselves. At such a small level the structural connections between space and time should become evident.

Heisenberg unwittingly chose to represent this fundamental connection between space and time by the uncertainties in their measurements. The two forms of the uncertainty principle separate pure space and pure time just as space and time were thought separate within the Newtonian model. But quantum mechanics differs from Newtonian mechanics in that the uncertainty principle states explicitly the extent to which space and time can be considered as separate entities. The mathematical statement that 'delta' x 'delta' p is 'greater than or equal to' h (as originally written by Heisenberg) does not include a time component or any other direct reference to time or change in time. It states there is a physical limit to measuring the stationary position in space (represented by x) of a moving object (represented by p) without referring to the object's position in time. The other form of the uncertainty principle, 'delta' E 'delta' t 'is greater than or equal to' h (as originally written by Heisenberg) simply states that there is a physical limit to measuring the fixed position of a material object in time (represented by t) as its motion relates to time (represented by E) without reference to the object's position in space. (Beichler, 1996) When stated in this manner, a compatibility between the Heisenberg uncertainty principle and special relativity can be established and the differences between the discrete nature of matter which determines relative space-time and the continuity of physical reality can be understood at a far more fundamental level than has been assumed by others.

On the other hand, this new interpretation of the Heisenberg uncertainty principle and the quantum concept itself clearly demonstrates that the quantum theory actually makes very important statements about the minutest structural components of the space-time continuum. These statements refer to the mathematical points where matter, space and time interact with electricity and magnetism to yield the continuous field of physical reality. This view is quite novel in present day science. The adoption of this interpretation could go a long way toward finding a remedy to many of the inherent problems of the various quantum theories. At least in this respect, this interpretation shares many characteristics with Bohm's latest theory.

By 1994, Bohm's theory had become legitimate grist for an article in *Scientific American* magazine. In his exposition of Bohm's theory, David Albert found that "this theory, ignored for most of the past four decades, challenges the probabilistic, subjectivist picture of reality implicit in the standard formulation of quantum mechanics." (Albert, 58) The very reason for Bohm's theory had not been hard to find.

> How does one distinguish those conditions in which the first category of laws applies from those in which the second category does? All the founders of quantum mechanics had to say was that it has something to do with the distinction between a "measurement" and an "ordinary physical process," or between what observer and what is observed, or between subject and object.
>
> For some time, many physicists and philosophers have viewed this state of affairs as profoundly unsatisfactory. It has seemed absurd that the best existing formulation of the most fundamental laws of nature should depend on such imprecise and elusive distinctions. The challenge of either eliminating or repairing that imprecision has

> emerged over the past 30 years as the central task of the foundations of quantum mechanics. It has gone by a number of names: the problem of Schrödinger's cat, for example, or of Wigner's friend, or of quantum state-reduction. I will refer to it by its most common contemporary name: the measurement problem. (Albert, 63)

Albert clearly and concisely pinpointed the central problem with quantum theory as well as confirmed that "many physicists" are still concerned with this problem. He identified the central issue as the measurement problem, the same that was addressed by EPR. And yet the measurement problem is related to the other problems with the quantum theory, as a whole as well as individual theory within the quantum domain.

> Finally, and most important, I must stress that all of what has been said in this article applies, at least for the moment, only to nonrelativistic physical systems. That is, it pertains just to systems whose energies are not very high, that are not moving close to the speed of light and that are not exposed to intense gravitational fields. The development of a Bohmian replacement for relativistic quantum field theory is still under way, and the ultimate success of that enterprise is by no means guaranteed. If such a replacement were somehow found to be impossible, then Bohm's theory would have to be abandoned, and that would be that. But as it happens, most other proposals for solving the measurement problem are in a similar predicament. The exceptions, once again, are the many-worlds and many-minds interpretations, whose relativistic generalizations are quite straight forward but whose metaphysical claims are difficult to believe. Much of the future course of the foundations of quantum mechanics will hinge on how attempts at relativization come out.
>
> In the meantime, the news is that a great deal more than has previously been acknowledged about the foundations of our picture of the physical world turns out to be radically unsettled. In particular, the possibilities that the laws of physics are fully deterministic and that what they describe are the motions of particles (or some analogue of those motions in relativistic quantum field theory) are both, finally and definitively, back on the table.

In this admission, Albert pointed out the simple fact that the quantum theory does not adequately account for particle interactions at extremely high energies, at relativistic speeds and in strong gravitational fields. He did not specifically mention QED and its offspring, but such an implication could not go unnoticed. Of even greater significance was Albert's final 'news' flash that there is far more to our physical world than expected and that our picture of reality, as expressed by the quantum theory, is "radically unsettled."

Even today, QED remains the only working theory of electron interactions. It still relies on renormalizations and does not unify electromagnetism with any other of the basic forces in nature. However, the great success of this theory has become the paradigm for extending quantum theory even further into other domains as a basis of unification. QED was followed by the Weinberg-Salam (Steven and Abdus) theory of weak interactions in the late 1960s. This theory was based upon a gauge field with a high degree of symmetry.

> This latter process appears to the experimenter as the scattering of a neutrino by a neutron, a phenomenon that is exceedingly weak. The theory, however, predicts an infinite effect! Unlike the infinities that arise in QED, those that occur in the W theory cannot be removed by the technique of renormalisation, because the mathematical

> structure of the theory lacks the vital internal symmetries necessary for the success of this manoeuvre. It wasn't until comparatively recently that a way round this impasse was discovered. One route to a renormalisable theory is to incorporate what is called *gauge symmetry.* Only mathematics can provide a proper description of this concept, but a simple example conveys a very crude idea. (Davies, #2, 201-203)

Fortunately, the symmetry was strong enough to avoid the "catastrophe of the infinities" which still haunts QED. (Davies, 1984, 123) The success of the Weinberg-Salam model in explaining one of the fundamental forces associated with the atomic nucleus strengthened the position of those who wished to apply the quantum to the 'mesonic fields' of the nucleus, now referred to as the strong nuclear force.

> In the Weinberg-Salam theory, the gauge symmetry is not broken in the underlying physical laws that govern the dynamics of the quantum fields. Instead, it is only broken "spontaneously". That is, the W (particle) acquires a mass only as a result of the particular (quantum) state it happens to occupy, not as an intrinsic attribute. This subtle distinction can be clarified with the help of an analogy with a more familiar kind of symmetry. ...
>
> Although these considerations might appear like nit-picking, they turn out to be crucial for renormalisability. In 1971 Gerhart 't Hooft of the University of Utrecht proved that the Weinberg-Salam theory is indeed renormalisable. Since then, several pieces of experimental evidence have supported the Weinberg-Salam model. These include effects caused by the exchange of an electrically neutral Z particle that exists alongside the W in the unified theory, and also a certain lop-sidedness in the electromagnetic scattering of electrons and protons previously restricted to purely weak force processes such as radioactivity.
>
> The success in curing the non-renormalisability of the weak force by unifying it with electromagnetism in an extended gauge theory encourages the search for a still larger gauge theory in which the strong, and perhaps gravitational forces are included. *9 August 1979* (Davies, #2, 204-205)

This work resulted in the theory of 'quantum chromodynamics' (QCD) and the concept of quarks. It seems that still smaller material units called quarks could represent nuclear particles. In this theory, the quarks are held together by the exchange of other particles called gluons. Like the Weinberg-Salam model, QCD is based upon gauge fields. And finally, in 1973 Sheldon Glashow and Howard Georgi published a theory of a 'grand unified force' that unified the strong and weak nuclear interactions. Although several other GUTs have been proposed, they all share the common characteristic of requiring the existence of quarks.

While gauge fields displaying various forms of symmetry replaced the renormalization process, a new group of problems arose for the new theories. Quite simply, the existence of quarks was necessary for the success of these theories, but the predicted quarks could not be detected in the laboratory. When they were finally confirmed by experiment, they could not be detected independent of the individual particles whose internal structures they explained. Quarks seemed to always be coupled together. At first, this was a problem for many scientists who thought quarks should have an independent existence if they were true particles, but that requirement just faded away as more experiments failed to confirm their independent existence.

> Consider, for example, what happened in the case of the missing quarks. By the 1960s, a theory had been proposed which said that an elementary particle is composed of three more elementary particles called quarks. Each quark was said to have a fractional electrical charge. The properties of these quarks were predicted, and all over the world physicists set up experiments to detect them.
>
> No quarks were ever detected. Did this mean that the theory had been falsified? Not quite, for the theory had only predicted the existence of quarks, not that anyone would actually see one. Moreover, as increasing numbers of elementary-particle experiments were performed, it became clear that three quarks could not explain the new results. Was the theory abandoned then? had it been falsified? Not at all; it was simply expanded to include six quarks instead of three. In addition, it was now proposed that quarks are in principle unobservable. (Briggs and Peat, 29)

The quark problem was never really solved. The theory of quarks and QCD was experimentally successful so the failure to detect quarks as individual particles was allowed to fade away as more scientists became accommodated to the idea. Yet no reason has ever been given why quarks must always remain bound within the elementary particles. Nor has any reason ever been given why they should be considered particles even though they seem to have no existence independent of the truly elementary particles.

Under these circumstances, the GUTs eventually evolved a single explanation of the four natural forces. The weak and strong nuclear forces were wedded to electromagnetism and gravity when the five-dimensional theory of Kaluza-Klein (Theodor and Oskar) was added to an extended GUT framework of ten dimensions. However, these theories were not without difficulties beyond the failure to detect quarks. The more popular GUTs predicted the existence of magnetic monopoles as well as a very long but finite half-life for protons. In both of these cases, experiments conducted over the past two decades have completely failed to detect the predicted magnetic monopoles and half-life of protons. These new failures have cast a shadow over the GUTs as well as the ability of quantum mechanics (or quantum mechanics alone) to explain the ultimate nature of reality. While these new theories have not suffered from the same problems of renormalization that plagued QED, they have not replaced QED with a theory which does not need renormalization, so the renormalization problem still exists at some level. The new theories have spawned their own concerns without direct reference to the prior renormalization problem.

Throughout this whole story, it has become evident that physicists are most bothered by the fact that no theory has come along which can unify the other forces of nature with gravity. This failure is all the more significant because of the more recent successes of GR and the growing concern that gravity cannot be unified with the other forces under the single banner of discrete physical reality that lays at the bottom of the quantum approach. Many scientists and scholars have been too quick to announce that Einstein's program of unification has been fulfilled by GUTs and the other quantum based theories that have been developed, without realizing that these theories have nothing to do with Einstein's dreams because Einstein sought a 'unified field theory' based solely upon the premise of the continuous field rather than discrete quanta.

Even today's superstring theories, touted as the long sought TOEs, have major problems. The superstring theories seem to have finally unified gravity with the other natural forces explained by the GUTs, but the cost has perhaps been too great. The superstring theories are said to represent the physics of the next century because it will be at least a century before mathematics has become sophisticated enough to find solutions for the superstring model. (Kaku, 160) On the other hand, the superstring theories predict particles that are so massive that it would take thousands of times greater energy than we can presently generate in the laboratory to experimentally verify their existence. In other words, it will be at least another century before a superstring theory can be experimentally verified, unless some new and unexpected scientific leap forward occurs. The superstring theories seem to give hope for a final solution to the unification problem, which is the major goal of science, but no more than hope.

What has become even more evident is the fact that the status of quantum theory in the scientific community is not as firm as it was once thought to be and the belief in the fundamental nature of the quantum as a basis for a final unification in physics is beginning to wane. The successes of quantum theory have been brilliant, this fact cannot be denied, but the successes are tainted by the philosophical concerns of the very scientists who display their advances in quantum theory so proudly. Too many scientists are willing to overlook or ignore the negative philosophical consequences of the quantum theory, at least so long as the theory is experimentally successful. But each level of advance in quantum theory brings a new set of problems and concerns that are related to the same philosophical problems that were defined decades ago. The quantum theory will always be incomplete until these problems are resolved and it can never be used as a basis for unification unless it is complete.

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