Bell's Theorem, Quantum Theory and Conceptions of the Universe.

edited by

Menas Kafatos
Department of Physics, George Mason University, Fairfax, Virginia, U.S.A.

KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON
Netherlands

1989

BELL'S THEOREM: THE FORGOTTEN LOOPHOLE AND HOW TO EXPLOIT IT

P.J.WERBOS
Department of Energy
Forrestal EI-621
Washington D.C., 20585
U.S.A.

ABSTRACT. Bell's Theorem rules out local, causal realistic physical theories. This paper describes a class of neoclassical theories which are local and realistic but which violate "causality" as that term is defined by Bell et al. For simple model PDE, I have already shown that certain statistical quantities obey a true Schrodinger equation; in the "non-collapse" view of quantum measurement, this in itself should be enough to reproduce known measurement relations. Schrodinger equations derived in this way are also anomaly-free (because the statistics of PDE must obey the PDE symmetries), a feature which is both crucial and difficult to obtain otherwise in unified field theories (supersymmetry).

1. Introduction

Hooker, at this workshop, has reviewed the philosophical dilemmas posed by Bell's Theorem, and the various approaches now used to escape these dilemmas -- all of which he finds unsatisfactory. This paper proposes a different escape route which, though difficult, would resurrect many of the elegant, classical ideas of Einstein and de Broglie.

The idea is to develop systems of nonlinear partial differential equations (PDE), whose transformed statistical moments obey Schrodinger equations. This paper begins by explaining this idea in more concrete terms. Next it discusses the implications for Bell's Theorem and the debate on the collapse of the wave function. It concludes with a brief summary of the progress to date in developing the required mathematics.

2. Background

A classical field theory consists of a vector field $\underline{\phi}(\underline{x},t)$, where $\underline{\phi}$ is an N-dimensional vector, and a set of PDE which $\underline{\phi}$ must satisfy. A statistical ensemble of solutions $\underline{\phi}(\underline{x},t)$ may be characterized by the probability distribution $\Pr(\underline{\phi})$ or by the corresponding <u>statistical moments</u>, which are widely used and studied in applied physics:

$$u_n(\underline{x}_1,i1;\underline{x}_2,i2;\ldots;\underline{x}_n,in;t) = E(\phi_{i1}(\underline{x}_1,t)\phi_{i2}(\underline{x}_2,t)\ldots\phi_{in}(\underline{x}_n,t)),$$

where E refers to expectation value. The collection of functions u_n

M. Kafatos (ed.), Bell's Theorem, Quantum Theory and Conceptions of the Universe, 81–83.

across all n is a vector in the same formal space as the ordinary wave function of quantum field theory (QFT). Because every one of the field configurations $\underline{\phi}$ must satisfy the original PDE, we may deduce that the vector $\underline{u}(t)$ must also obey a certain dynamic equation, *for any ensemble* of solutions. This dynamic equation is awkward; however, by performing *similarity transformations* on the vector $\underline{u}$ (similar in spirit to Fourier transforms), we may arrive at a tractable equation which is very similar to the Schrodinger equations of QFT in those cases which I have studied.

The neoclassical approach to field theory is to study more complex PDE, to derive the resulting Schrodinger equations, and to compare them against *both* the Schrodinger equations of high-energy physics *and* the empirical data (which do not always fit the usual Schrodinger equations). These PDE are the underlying physical theories.

3. Relation to Bell's Theorem

In this workshop, many speakers said that Bell's Theorem makes us choose between locality or realism in physical theory. This seems to rule out my approach, which looks for PDE which are both local and realistic.

However, the original papers by Bell, Shimony et al stated that they rule out "local, causal hidden variable theories;" in other words, a local hidden variable (realistic) theory would be acceptable, if it did not obey "causality." Concretely, "causality" was defined as the existence of conditional probabilities for measurement outcomes, conditional upon inputs to the experiment.

Other speakers here have discussed the causality loophole somewhat. Pitowsky, for example, referred to it as the assumption of "probability theory." Others proposed a C* probability logic to replace probability theory. Here, however, I am focusing on a more concrete aspect of this loophole: the implicit assumption of *time-forwards* causality.

Time-forwards causality -- which is built into the Bell-Shimony definition of "causality" -- does more than assume the existence of conditional probabilities. It assumes a kind of Markhov property as well. It assumes that the probability of a given photon state emerging from an experiment should be conditional upon the *initial* experimental setup, but *not* upon the choice of final measurement. It assumes that there is no causal effect *backwards* in time from the measurement device to the earlier photon state. In formal terms, it assumes that the probability of photon states conditional upon *both* measurement-device and initial information *equals* the probability conditional upon the initial information by itself. Years ago, such a Markhov process assumption was widely used in computer vision, but downgraded when it was shown that Markhov random fields (which are similar but do not assume anything about the time-direction of causality) are more realistic in most cases and cannot be reduced to Markhov processes.

My argument is that PDE which are time-symmetric (or CPT-symmetric) should not be *assumed* to obey time-forwards Markhov statistics any more than Markhov random fields do. In fact, at the microscopic level, one would expect them to obey *time-symmetric* causality, in which the probabilities depend on *all* boundary conditions - past *and* future - for exactly the same reasons given by de Beauregard for quantum systems. If we throw out the axiom of time-forwards causality, it does become tricky to calculate the statistical implications of PDE; our efforts in this direction have led to measurement equations strikingly similar to those of de Beauregard, based on similar physical reasoning, and consistent with the general structures of QFT. In summary, such PDE are not ruled out by Bell's Theorem, since they do not obey time-forwards causality.

Note that time-symmetric causality was also invoked by Einstein to explain the photoelectric effect within the context of wave theory.

4. Relation to Collapse of the Wave Function

The argument above does not establish that neoclassical theory can reproduce the forecasts of QFT in specific cases; it merely disproves the idea that neoclassical theory is ruled out by Bell's Theorem.

Once we accept the idea that neoclassical theory might work, however, we must ask what happens if we can in fact derive interesting and useful Schrodinger equations from classical PDE.

The general view at this workshop - as presented by Albert and Kochen - is that collapse theories are on their way out. Even though Everett's arguments are seen as weak, people tend to accept Everett's conclusion that the measurement relations observed in physics can be derived without collapse, from properties of the Schrodinger equation itself. If this conclusion is true, then the mere existence of such a Schrodinger equation obeyed by the moments of a classical field would imply that the quantum-mechanical measurement relations would apply as well to that system. Since Schrodinger equations have already been derived for the statistics of simple PDE, this issue is already resolved in principle; the task at hand is to go on to study more realistic PDE, reflecting the complex issues of high-energy physics. This is far beyond the scope of a three-page summary, however.

5. Progress to Date

So far I have tried two approaches. In "A True Schrodinger Equation for the Statistics of Classical Fields" (submitted to **Physica D** in 1988), I study a complex field ϕ, obeying a Klein-Gordon equation with a $g\phi^2$ term added to the PDE. (Work by Wiener and Martin is also discussed.) I derive a Schrodinger equation with Hermitian Hamiltonian, built up from creation and destruction operators with the usual energy denominators of QFT. I also cite earlier work which reproduces Feynman integrals, rather than Schrodinger equations, which allows use of a more elegant formalism which is transparently relativistic; in that work, I reached the point of studying Maxwell-Dirac systems and soliton properties in generic terms, but I have shifted to the 3D approach because of the need to connect with today's mainstream (and to make the argument above). In 3D, even a fully acceptable ϕ^4 theory seems to require exploitation of the symmetry relations inside the moments-density matrix when conjugate fields are represented as additional field components in $\underline{u}$.