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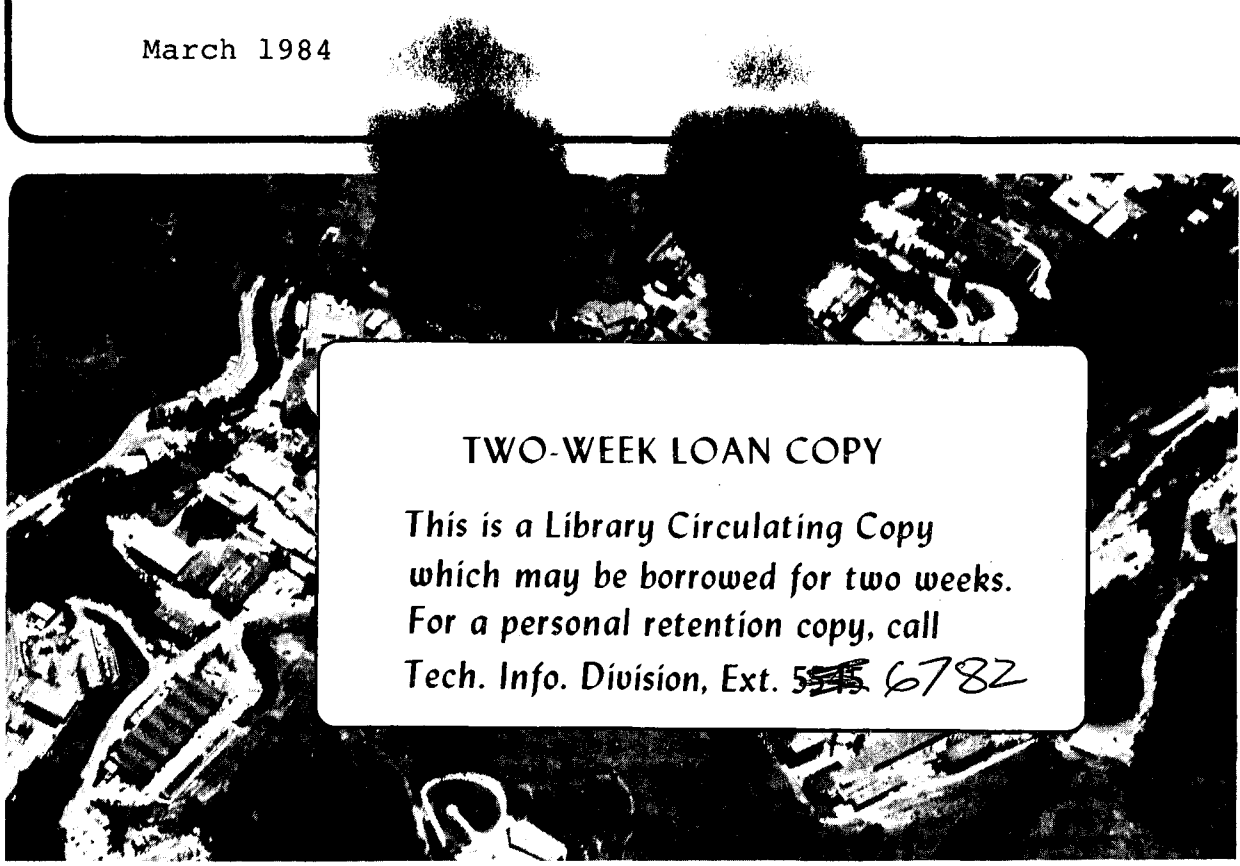
March 1984



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Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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March 1984 LBL-17576

TIME AND QUANTUM PROCESS*

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Abstract

Recent advances in the quantum theory of light may provide the resolution of the fundamental problem that had blocked the development of a quantum theory of Process. The problem was that, although the world of macroscopic appearances conformed to the precepts of classical physics, no corresponding exact classical description emerged naturally from the quantum formalism. The resolution of this problem leads naturally to a theory of relativistic quantum process. The theory does not depend upon human observers, but describes an objective process of becoming. In nonquantum relativity physics, according to Einstein, "becoming in three-dimensional space is somehow converted into being in the world of four dimensions." Relativistic Quantum Process converts this to becoming in the world of four dimensions.

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* Presented at Conference: "Physics and the Ultimate Significant of Time," March 16, 1983, Center For Process Studies, Claremont, CA 91711.

This work was supported by the Director of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

To comprehend the significance of time in modern physics one must distinguish two very different kinds of time. The first I call Process Time, the second Einstein Time. Process Time is the time associated with a cumulative process whereby things gradually become fixed and settled. Einstein Time is the time part of the spacetime continuum of contemporary physics.

Contemporary physical theory establishes no connection at all between these two kinds of time. For it says nothing about Process. It deals rather with the content of observations. Each observation has a content that includes, in principle, a clock and ruler reading. These readings assign to the observation a place in the spacetime continuum. But whether the data represented in one observation become fixed and settled before or after the data represented in some other observation is not determined by contemporary physics: one can equally well imagine either that everything becomes fixed and settled all at once, in some single act of creation, and hence that neither Process nor Process Time exists, or, alternatively, that things become fixed and settled in some definite order. These two possibilities are not empirically distinguishable. Indeed, Einstein's analysis of the meaning of time in physics made it clear that time enters physics only through the content of observations that say nothing at all about the order in which things become fixed and settled. His analysis effectively banished the concept of Process from the physical theory of his era.

Of course, in the deterministic framework within which Einstein himself worked Process could be no real issue. The deterministic laws ensure that everything is fixed and settled by the initial act of creation. Thus there could be no Process. Hence the real impact of Einstein's analysis of time came only later, when quantum theory introduced indeterminism. In this latter context the idea of Process arises naturally, at least at the conceptual level. But the founders of quantum theory, following Einstein's lead, circumvented the problems associated with Process by asserting that the quantum-mechanical formalism "merely offers rules of calculation for the deduction of expectations about observations obtained under well-defined experimental conditions specified by classical physical concepts."[1]

Quantum theory has, nevertheless, one feature that suggests that it should be formulated as a theory of Process. The wave function of the quantum theory is most naturally interpreted as representing "tendencies" or "potentia" for actual events. This intuitive idea of the meaning of the wave function was first made explicit by David Bohm in his 1951 textbook, Quantum Theory.[2] The idea was endorsed by Heisenberg,[3] and probably agrees with the intuitive ideas of most quantum physicists. However, in spite of this natural occurrence within quantum theory of this basic Process-notion of "tendency" the theory was not originally formulated as a theory of process. Severe technical difficulties blocked the way.

Of the many difficulties blocking the development of a quantum theory of process I shall mention only two. The first is that the world at the observed macroscopic level conforms generally to the concepts of classical physics, whereas the world at the atomic level is represented by a very different kind of mathematical structure. In particular, at any instant of time a system of n particles is represented in quantum mechanics by a function in a space of 3n dimensions, whereas the world of classical physics resides in a space of 3 dimensions. There appeared to be no mathematically and physically acceptable way to relate in any exact way the quantum structure in 3n dimensions to classical physics in 3 dimension, without referring explicitly to "our observations," and exploiting the empirical fact that we describe the content of our observations by using classical concepts. This procedure was considered unsatisfactory by some scientists and philosophers because it injects human observers into the structure of basic physical theory. Their objection was met by insisting that science should deal directly with what man can know, or expect. This second point of view has prevailed, partly, at least, because no natural Process formulation of quantum theory has appeared.

A second difficulty was that the identification of the "actual events" appeared to require the notion of irreversible processes, and this notion seemed ill-defined on a fundamental level.

Recent technical advances appear to have opened the way to the development of a natural quantum theory of Process. The two key ingredients are the S matrix, and some recent developments in the quantum theory of light.

The S matrix was introduced into quantum theory by Wheeler, and was used by Heisenberg to get around a serious technical problem. This problem had its conceptual side. Relativistic quantum theory had taken over from non-relativistic quantum theory the notion of the state of a system existing over all of space at a single instant of time. This concept does not conform to the relativistic precept of the meaninglessness of simultaneity. On the other hand, on the practical side, the introduction of the requirements of the theory of relativity had engendered certain divergences, called "ultraviolet" divergences, that caused the state of the system at an instant of time to become mathematically ill-defined.

Heisenberg observed that both problems could be resolved, without losing any of the empirical content of relativistic quantum theory, by abandoning the concept of the state of the system at an instant of time, and adopting, instead, the idea that the basic quantity in relativistic quantum theory was the S-matrix.

The S-matrix viewpoint would appear at first to eliminate completely any possibility of developing a quantum theory of process. For the S matrix describes, by definition, only the quantum transitions from states in the infinite past to the states in the infinite future. It

omits all description of what is going on in between. Moreover, space is also eliminated. For the basic variables of the S-matrix are not the variables that represent position, but rather variables that represent states of inertia -- states that if left undisturbed would endure unchanging for all eternity.

The S-matrix viewpoint appeared beset also by a serious technical difficulty: the S-matrix seemed to be mathematically well defined only in an approximation where light was ignored. This was the famous infrared catastrophe. Yet light certainly cannot be ignored in any adquate description of the world in which we live. For light (i.e., the electromagnetic interaction) is responsible for the binding that holds together both the objects of everyday experience and our bodies themselves. Light is the light by which we see, and is responsible for the sound by which we hear, etc.

A completely satisfactory resolution of this infrared catastrophe has only recently been found.[4] This resolution is based on the discovery that the light emitted by matter has a well defined classical part. This classical part is a function defined over the four-dimensional spacetime continuum. Thus the incorporation of light into the S matrix -- and light is the very ingredient most responsible for the form of the world in which we live -- automatically brings into the S matrix formulation of relativistic quantum mechanics an <u>exact</u> classical level of

description coordinated to the ordinary four-dimensional spacetime continuum of the theory of relativity.

This technical development provides the foundation for a natural formulation of a quantum theory of Process. Process is considered to consist of a well-ordered sequence of actual events. Just prior (in Process Time) to event number n there are several possibilities for what might become actualized. Let these possibilities be labelled by the set E_n of indices e_n. One of these events will become actualized. Let it be called a_n.

For each n there is a corresponding spacetime region R_n, determined by Process. For each possible event e_n there is a projection operator $P(e_n)$ that restricts the classical field inside region R_n to some subset of the set of all conceivable classical fields in R_n.

Let $S(e_n)$ represent the S matrix subjected to the condition that the classical fields be limited to those allowed by the product of projection operators $P(e_n)P(a_{n-1})P(a_{n-2})\ldots$ Let d_{in} be the initial density matrix, and let $d(e_n)$ be $S(e_n)d_{in}S^+(e_n)$. Then the probability for event number n to be e_n is $\mathrm{Tr}d(e_n)/\mathrm{Sum}\ \mathrm{Tr}d(e_n')$ where the sum appearing in the denominator is over all e_n' in E_n.

The set E_n of possible events e_n is restricted by the following bifurcation condition, which will be discussed later: the various operators $d(e_n)$ for e_n in E_n have disjoint supports in the multiparticle momentum space upon which they are defined.

This Process formulation of quantum theory contains no explicit dependence on human observers: it allows quantum theory to be regarded as a theory describing the actual unfolding or development of the universe itself, rather than merely a tool by which scientists can, under special conditions, form expectations about their observations.

This quantum theory of Process is in general accord with the ideas of the physicist, logician, and Process philosopher Alfred North Whitehead.[5] In particular, the actual is represented not by an advancing, infinitely thin slice through the spacetime continuum, but rather by a sequence of actual becomings, each of which refers to a bounded spacetime region: event number n is represented, within physical theory, by a restriction on the set of classical fields allowed in the bounded spacetime region R_n. We have, therefore, neither becoming in three-dimensional space nor being in the four-dimensional world,[6] but rather becoming in the four-dimensional world.

Event number n is represented in physical theory by a restriction upon the classical fields allowed in the bounded spacetime region R_n. This restriction induces, through the quantum formalism, changes in the tendencies for the next event. These changes in tendencies are manifested over all of spacetime -- i.e., even if the region R_{n+1} is spacelike situated relative to R_n. This change in tendencies is the nonlocal change that is associated with

the collapse of the wave function in some formalisms, and, more generally, with Bell's theorem.[7]

The tendencies are calculated in the quantum formalism by using Feynman's sum over all spacetime paths. In the S matrix formulation, these paths extend in time, in general, from minus infinity to plus infinity: they do not terminate in the region R_n. Thus as regards tendencies the entire spacetime continuum of the theory of relativity theory is involved in each step of the process of becoming. But as regards actualities each actual event is associated with a bounded region in spacetime.

The conception of Process described above differs from Whitehead's because it has no place for his "contemporary events." However, because Whitehead stressed so often that these awkward contemporary events were forced upon him by the physics of his time, rather than by his general principles, it is, I think, safe to infer that had he known about the nonlocal connections entailed by Bell's theorem he never would have mutilated his theory by the introduction of these contemporary events.

A brief remark about gravitation is needed. The gravitational field is a gauge field that can be expected to have a classical part similar to the one associated with light. But the details have not yet been worked out. So I have simulated here the expanding universe in which live by a flat space and an initial state in which all constituents are rushing toward the spacetime region of the big bang. This allows S-matrix ideas to be used. The final state can

be conceived to be a state where the various momenta are all quite accurately defined. The partially neglected gravitational interaction will then turn the outgoing particles into the incoming particles for the next big bang, etc. I have neglected, therefore, both the very long-range part of the gravitational interaction, and also any short-range parts that cannot be adequately approximated by gravitational interactions in a flat space.

I turn now to the questions of irreversibility and the connection of the present work to the one presented to this conference by Prigogine. The traditional problem, as regards the identification of actual quantum events, is that one does not know, with certainty, whether the event is irreversible until one knows exactly what conditions the resultants of the event will eventually encounter: the conditions might conceivably be exactly right to effect a coherent recombination of these resultants. This problem is resolved here by using the overall spacetime viewpoint of the theory of relativity and of S-matrix theory, and calculating all probabilities from the asymptotic state corresponding to time = $+\infty$. The intuitive idea of physicists is that once the differences between the several possible results have evolved to a level where the different possibilities correspond to different motions of macroscopic objects, or to different macroscopic electromagnetic fields, then the subsequent time evolution will not be able to bring <u>all</u> of the 10^{23} momenta corresponding to the two alternative possible results back into coincidence. For the

interaction required to bring the various parts back together will transfer momentum to other objects, etc. This normal intuitive idea of the condition that defines an actual event is formulated here as the bifurcation condition, which demands disjunction at time = $+\infty$ of the momenta associated with the alternative possibilities.

Although this bifurcation condition corresponds to normal intuitive ideas about the conditions needed to define an actual quantum event, the question arises to what extent this condition can be analyzed with mathematical precision. Here it appears that the mathematical methods employed by Prigogine might prove useful. For in both cases the concern is with the behavior of trajectories when extrapolation is made into the distant future. Prigogine's methods, though dealing in the first instance with classical systems, nevertheless involve probability functions, which in our case follow directly from our use of quantum theory. Conversely, the general framework described here might provide a satisfactory conceptual underpinning for Prigogine's work. His method involves the introduction of a transformation constructed to achieve the desired result of breaking the symmetry between the two directions of time. But the physical origin of this transformation is unclear. In the present framework the symmetry is broken by Process itself. Thus the present work, and that of Prigogine and associates, may be two mathematical aspects of a single solution to the problem of understanding Process within contemporary physics.

Scientific application of this theory of quantum process may come first in connection with the problem of molecular structure.[8] Indeed, evidence already exists that the assumption needed for the application of Copenhagen interpretation, namely that the quantum system can be considered essentially isolated from its environment, fails at the molecular level, and that, moreover, the interaction with environmental infrared photons is responsible for the emergence of classical properties at the molecular level.[9]

REFERENCES

1. Niels Bohr, Essays 1958-1962 on Atomic Physics and Human Knowledge (Wiley, New York, 1963) p. 60;
   Henry P. Stapp, Amer. J. Phys. 40 1098 (1972)
2. David Bohm, Quantum Theory, (Prentice-Hall, 1951)
3. Werner Heisenberg, Physics and Philosophy (Harper and Rowe, New York, 1958) Ch. III.
4. Henry P. Stapp, Phys. Rev. D28, 1386 (1983)
5. Alfred North Whitheead, Process and Reality (Macmillan, New York, 1929);
   Henry P. Stapp, Foundations of Physics 9, 1 (1979)
6. Allusion is made here to Einstein's famous assertion: "becoming in the three-dimensional space is somehow converted into a being in the world of four dimensions." For a discussion of Einstein's vacillating views on this question see Milic Capek in: (i) Bergson and the Evolution of Physics, ed. P.A.Y. Gunter (The University of Tennessee Press, 1969); (ii) The Voices of Time, ed. J.T. Fraser (George Braziller, New York, 1966); and (iii) The Concepts of Space and Time, Boston Studies vol. XXII, ed. Milic Capek (D. Reidel Publishing Co. Dordreht, Hulland/Boston, 1976).
7. John S. Bell, Physics (N.Y.) 1, 195 (1964);
   Henry P. Stapp, Bell's Theorem and the Foundations of Quantum Physics, Lawrence Berkeley Laboratory Report LBL 16482 (1983)

8. R. G. Woolley, J. Amer. Chem. Soc. 100, 1073 (1978);
   Israel J. of Chem. 19, 30 (1981)
9. Peter Pfeiffer, Chiral Molecules -- a Superselection Rule Induced by the Radiation Field Thesis, ETH Zurich. and in Quantum Mechanics in Mathematics, Chemistry and Physics, Edited by Karl E. Gustafson and William P. Reinhardt, (Plenum 1981);
   Hans Primas, Chemistry, Quantum Mechanics, and Reductionism, Perspectives in Theoretical Chemistry, Lecture notes in Chemistry, Springer, Berlin 1981.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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