CONNECTIONS BETWEEN EVENTS IN THE CONTEXT OF THE COMBINATORIAL MODEL FOR A QUANTUM PROCESS

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I. PARAPSYCHOLOGY AND COMBINATORIAL MODELS

In this paper I describe a discrete or combinatorial model for a quantum process. In accordance with the policy of this conference I am describing work which I am doing as an attempt at a contribution to physics in its own right, but I also believe the enterprise, of which the construction of this model forms a part, to be relevant to parapsychology.

In the first place, this relevance comes from the connectivity of events in space and time. To the best of my knowledge, no paranormal effects have been discovered which exhibit any consistent and precisely formulable dependence of that effect on spatial separation of subject from whatever he is relating paranormally to. Thus, far from the effectiveness of, say, PK falling off as the square of the distance of the subject from the object being influenced, most observers are inclined to say that that distance should be regarded as essentially irrelevant to whatever it is that is going on. It is often said that a large spatial separation may constitute a psychological barrier to a successful paranormal effect in that the subject feels a strangeness which puts him off, but that in reality whether the subject is at arm's length or half the world away makes no difference. To assume as high a degree of independence as this would, however, be to make the error of jumping to a conclusion opposite from the conventional scientific one—that of assuming that there must be some exact law of distance dependence.

Whichever of these poles evidence may finally take us toward, it seems for the moment that the safe course is to attempt to find laws governing the paranormal which force us to no conclusions regarding distance dependence. This requirement is an unexpected and disturbing one if we take anything along the lines of laws of nature as we find them in physics as our exemplars for laws of the paranormal. Physical laws as we normally understand them take a high degree of consistency in measurement of variables in space and time as a prerequisite for their formulation, and to attempt such a formulation is a very major undertaking. Apparently the only way to work in this direction is to start with discrete or combinatorial structures which have no initial interpretation in terms of a space-time continuum and to develop any such interpretation progressively and deliberately. In this paper, I shall be describing one such combinatorial approach.

The second reason for thinking there might be a connection between models of the type I describe and the paranormal is that there appears to be some evidence that paranormal effects, particularly of the kind that have recently become well known through Uri Geller, may influence quantum events directly. This evidence is not yet strong but it does begin to seem likely that processes in which there is a simple dependence on events at the quantum level are the most susceptible to Geller's influence. He seems to be able to deal with them more directly and reproducibly than with ordinary assemblages of atoms in pieces of material. Even if this is not the case, it is important to realize that in these PK phenomena we are evidently dealing with something outside our normal experience in the particular sense that the fields which one would usually expect to be associated with the changes (e.g., in bending of metals) are absent. At least they have certainly not been consistently detected. This fact suggests further that the quantum level may be where things start.

Such a possibility is not ruled out by current quantum theory, since we have no idea, for example, of what causes the collapse of the wave function in the observation situation, and something has to cause it, but on the other hand, it seems that existing ideas are ill-adapted to exploit the possibility, and models in which the quantum event is constructed as a result of some explicit processes in a background may open the way to a more appropriate manner of thought. In the model I am proposing, extremely counterintuitive characteristics are postulated for the particles but the paradoxes which still exist in the current treatment are avoided.

Rosenfeld[1] introduced the terms "objectivist" and "subjectivist" into the philosophy of quantum theory. Interpretations in which the person who performs the experiment must be explicitly incorporated into the description of what happens are called *subjectivist* by him. An *objectivist* interpretation, by contrast, is one where the description can be given from the outside without any essential reference to an agent or subject. In this paper, I reject Rosenfeld's attempt to specify objectivism on the grounds that it postulates complementarity and that, in the complementarity approach, the question of the place of the observer or of the profound role of the measuring process still remains to be understood.

In most theories of quantum phenomena it is supposed that the probabilistic character of the laws governing the phenomena is connected with the fact that in order to make an observation one has to use a quantum particle (taking that term for the moment to include photons). The accounts vary, however, in the way in which they establish the connection. I shall take the position that it is of the essence of the quantum situation that one has no privileged access to any reality behind the appearance of particles which could short-circuit the stage of using the particles to get information. One could characterize current quantum theory, so far as its logical and epistemological foundations are concerned, as a theory which attempts to give this primacy to the operational place of the particles, while retaining the essentials of the classical background—namely by retaining concepts which derive their meaning from situations in which indefinite refinability of observation is presupposed. There is an obvious incompatibility here, which in quantum theory is bridged (in ways too well known to need repetition) by the idea of a participating observer. In effect, quantum theory says you can have your indefinitely refinable background as well as your operational primacy of the particles because whenever the consequences of these principles result in conflict, you can postulate that the effect of the observation process justifies neglecting consequences that you would otherwise deduce from existence of the background.

Hence I wish at once to say that the notion of "participation" in current quantum theory is the most profound discovery of that theory and that in its usual forms of expression, it is so misleading as to be wrong. It is profound because it recognizes the operational primacy of the particles. It is wrong because it does so only at the expense of importing one inappropriate philosophy (the subjectivist observer) to cancel out another equally inappropriate—that of the background which is independent of our ways of discovering it.

A writer whose thinking has brought him within range of my position is Wheeler.[2] Wheeler had, in the last few years, come to the conclusion that the structure of space-time must be regarded as just the last of a chain of cherished preconceptions of physics which have had to be abandoned as we get knowledge of unfamiliar and extreme conditions which obtain in the universe (for example in black holes). If space-time had to be abandoned then, Wheeler argued, the hunt would be on for combinatorial conditions which gave rise to space-time topology and, derivatively, to space-time geometry, under the normal circumstances, but which, being more fundamental, could give rise to other topologies and geometries in other more extreme circumstances. Just recently, Wheeler[3] has moved further to say that of the basic principles upon which people have seen quantum theory to be based (uncertainty, exclusion, complementarity, and so on) the principle that alone really is inescapable is that of "participation" (and I have taken this term from Wheeler). Wheeler seems to want to separate the participation idea from that of an all-too-anthropomorphic observer, because he argues that his structural or combinatorial relations had—in virtue of the need for economy in basic hypotheses—to exhibit that very *participatory* character which he had argued to be the essential basis of quantum physics. His own hunch about how to achieve this reconciliation was to look at Gödelian situations in mathematical logic on the combined grounds that (a) the binary choices in logic are compatible with the discreteness of quantum theory and (b) that the participatory idea is exemplified. I cannot myself see that the Gödelian analogy can be useful because it depends on the actions and decisions of a mathematician and gets us back to the subjectivist philosophy, but it is interesting that analysis of the participation notion has led Wheeler to postulate the existence of a class of combinatorial structures which depend upon a binary algebra and upon which physics should be based. The mathematical model used in this paper will have this character.

II. A SPECIFIC MATHEMATICAL MODEL

The approach presented in this paper has its experimental reference in the macroscopic observation of the elementary particles. That is to say, I depart from the classical view according to which the properties of space-time are determined by macroscopic measurement independently of observation and according to which we treat the particles as individuals in isolation from each other and from their surroundings. For me, the "observation" or "measurement" process considers a particle and its environment as a unity.

I shall introduce this approach using as an example a combinatorial mathematical structure generated from a finite set of initial elements which I shall expound separately from its interpretation. The initial elements are not interpreted as particles of any sort, nor, indeed, as any other physical entity. According to this approach, each interpretable element can only be interpreted given the existence of the whole structure but, at the present time, only a small part of what needs interpretation has received it. Even though the individual mathematical quantities in the structure do not correspond directly to observables, we still have to insist that they and their relationships must correspond to something in the universe because some properties of the structure are given an interpretation and because they are of the same kind as the rest.

The environment in which a particle has to appear, and therefore the characteristics of the particle, is specified by a particular configuration of the mathematical structure at each stage of development and it would be incorrect to make independent provision for interpreting the behavior and the characteristics of the particles. Rather, what we do is to impose a particular configuration upon the mathematical structure. This corresponds in the physical interpretation to the way in which one "prepares" a particle in a particular state in current quantum theory.[a] The idea of the imposition of a particular configuration or constraint upon the mathematical structure will be described later in the paper.

This approach provides an interpretation of certain combinatorial relations within the structure. Thus, for example, the selection of particles according to those which (as we should normally say) travel in one plane as a result of the particular kind of field and particular arrangement of slits will correspond to a particular constraint on the mathematical structure.

Any model of the sort I have described must have a technique for describing increasingly complex structure, since the device open to ordinary physics in which we simply imagine a multiplicity of systems of the sort we have constructed spread out in a space is not available to us. In fact the way we make our choice of a method for extending the system is extremely important and depends upon extending further the idea of a constraint which has just been described. *We construct a new system out of the constraints which have already been imposed.*

The simple combinatorial structures that I have so far introduced are to be identified, using the notion of constraints, with the operational specification of particles. This specification uses classical dynamical concepts—though in a way that allows for the fact that our knowledge is in terms of discrete interactions. The aspects of the structure available for interpretation in terms of particle processes are constraints imposed upon the random generation of the finite set. In

[a] I am assuming the view which is given central importance by some writers on the quantum theory that a "particle" includes in its own proper specification the preparation of its state.

any application of the model to the world it will be possible to attribute causes to apparently random processes by imagining the investigation pushed further; but however far it is pushed, a practical limit must come at which we treat the process as random. Randomness, therefore, always expresses a practical limit on the extent of our knowledge, and within that limit, knowledge is expressed by constraints upon the field over which the randomness operates.

The following points about the relation of our structure to physics as we normally understand it may be noted:

(1) The mathematical structure with generating rules for creating new elements has a finite character. Hence there is never a representation of the physical continuum. The continuum is viewed rather as a possibility of further construction.

(2) The existence of a background continuum, while it may be anything from a theoretical convenience to a theoretical necessity, must only be assumed in so far as it has been justified. Particles do display attributes (like a high degree of coherence in describing a path) in particular kinds of situations (such as when a particle has enough energy to ionize particles and define a path with some semblance of smoothness). Instead of taking up the idea of the continuum at an intuitive level, as happens in current quantum theory, these situations have to be described theoretically and set up mathematically. This process of setting up the mathematical background corresponds to the experimental setting up of the particle experiment and the *preparation of the state* of the particle. Since, however, the quantum world provides knowledge in discrete steps, there is no reason to expect that a rigorously operational mathematical development would incorporate the idea of the continuum, except as an ideal limit.

(3) In order to set up the mathematical background, we impose constraints and these represent the particular experimental conditions in question.

(4) It may seem surprising that if our macroscopic experience is part of the same universe as that which is continually being created by these sequential processes, it should exhibit so much stability. Certainly a great task remains in propounding any account of classical physics in terms of our structure, but we should remember how

specialized an environment is provided for us by (a) the conditions of that part of the universe in which we happen to live, (b) the evolution of our sensory mechanisms including that aspect of them which gives great prominence to a uniform spatio-temporal background, (c) our own efforts in setting up experiments.

To illustrate the concept of "constraint" and the way in which it can relate to spatial specification, let us consider the idealized steps one takes in a typical experimental situation.

(1) We observe (or have records of) individual particle processes for which "collision" or "interaction" is perhaps the correct metaphor with its discrete connotations. (We should not be misled by the tracks in bubble chambers or cloud chambers into giving operational centrality to the *path* with its classical continuum overtones, for these "paths" are collections of individual events and are only a special case as becomes clear from the high-energy situation.)
(2) We infer successively motions and changes of motion (accelerations) from these observations.
(3) We apply the Newtonian insight in a nonmetrical form and ascribe the accelerations to *forces*.
(4) We introduce a new form of words in which the forces are described in terms of *fields* of different sort depending on the nature of our knowledge of the accelerations; at this stage of complexity of description a field has no existence *independently* of a particle. To represent constraints we use ordered sets of the symbols 0,1. Such a set will be referred to as a "column."

The constraints act in such a way as to restrict the generation of columns to some d.c. susbspace,[b] smaller than the entire space of all possible columns of the given order j, say. The simplest way to represent this generation process is by the successive operation on the set of columns of a $j \times j$ matrix over Z_2 having the desired d.c. subspace

[b] A d.c. subspace (discriminately closed subspace) is a subspace closed under element-wise addition mod 2 between columns from which the null column is excluded. The use of this concept is explained in Ref. 4: For the present purpose one may read "closed under addition mod 2" for "d.c.," but I retain the latter usage here.

as an invariant subspace. This generation process thus acts in parallel, as it were, to the discrimination process.

The matrix which thus represents the constraint and its operation is itself one of a new and more complex set of entities. Since these new entities are themselves in the universe and subject to the same conditions as have already been discussed, we expect them to generate subsets. In this way, we introduce a notion of *inducing* subsets at a new level. I shall consider cases where a disturbance of the system, represented by an element at the new level, produces something new—the essential idea being, that if and only if it falls outside the d.c. subset already determined by the initial constraints then it is not new.

The simplicity and weakness of this basis evidently allows very many different mathematical developments. This is due, firstly, to the fact that much work remains to be done both in tightening the physical thought and in investigating the mathematics, which, as one might expect with such a basis, remains conceptually simple but becomes, combinatorially, extremely complex; and secondly to our intention that certain apparently conventional choices in the mathematics should correspond to features of a particular physical situation to which the mathematical structure is applied, and each such conventional choice has to be justified.

We can extend our structure by considering mappings defined on the mappings and so on; that is, we can extend it by writing the $n \times n$ matrices as n^2 columns, over the set of which we consider mappings which preserve d.c. sets. This gives rise to a hierarchy, the levels of which contain columns of ever greater order—the order rising by the square.

The foregoing mathematical steps are intended to provide a model for the operational specification of the properties of particles in terms of progressive knowledge of their behavior, and it is convenient to think of the mathematical steps in this construction in a hierarchical system as being performed in a computer program.

If one considers actual models involving hidden variables as I shall do, rather than constructing existence theorems about them, then the choice is immediately impossibly wide. This is probably why people don't work that way. In the search for principles which restrict the freedom to what is manageable, the principle of the hierarchy in which the simple entities of the quantum world have a background of progressively more complex interactions is a very natural one; indeed one which it is difficult to avoid.

The purpose of the following model is to represent a set of interacting processes which underlie the quantum processes as an operating unit and this, for want of a better word, I shall call the "engine." More than one such unit can then be used together to represent states of partial correlation. In the present paper the correlations between different states of the engines will be associated with particular states of spin. A particular state of spin is a constraint upon the transformations that take place in a set of discrete processes which are caused by similar larger sets in a hierarchy. The causation is represented by mathematical operation.

III. THE MODEL

(1) There exists a set $I = I(A, B, \ldots, n$ terms) of binary strings (strings consisting of the binary units 0, 1) of equal length l at a given time.

(2) There exists a set of names assigned to the strings in (1). These are equal strings $a, b, \ldots, n$ terms of length l and the name a will be given to string A, and so on.

(3) A generating process α is defined for constructing elements of I. If P and Q (P and Q in I) are called, then a new string R is constructed such that for all P, Q there exists a unique R, and such that

(4) Various nonzero strings P, Q are called and combined by the discrimination operation (described previously) to produce further strings which are added to the set I. The strings are selected by an algorithm whose initiation is again outside the model, the strings being referenced by their names.

(5) Further algorithms generate matrices corresponding to constraints so as to establish the next hierarchical level, as described above (this section).

(6) Strings $P_1, P_2, \ldots, P_t$ $(t \leqslant n)$ are called and a matrix $J(P_1, \ldots, P_t)$ constructed having the discriminate closure of the set $\{P_1, \ldots, P_t\}$ together with the zero string as an invariant subspace. $J(P_1, \ldots, P_t)$ is regarded as a string of l^2 elements.

(7) Concurrently with (6), a name β $(P_1, \ldots, P_t)$ is constructed from the names $p_1, \ldots, p_t$ (where p_i is the name of P_i) and forms the name of $J(P_1, \ldots, P_t)$ at the next hierarchical level.

(8) After the generation of each matrix J, an element P is selected from I and used to generate the strings $JP, J^2P,$

$J^3P,\ldots,J^kP = P$. If any of these elements are not in I, then one changes to one *lower* level, and repeats from (6); or if one is already at the lowest level, stops. If the elements J^iP are all in I then a new P is selected and the process repeated. If $J^iP \in I$ for all $P \in I$, then a new matrix is to be generated as in (6).

(9) If the process has not terminated after a preassigned number N of operators, terminate it.

This "engine" is arbitrarily restricted at the two ends: at the level of minimum complexity where the elements are given an interpretation in terms of a discrete analog of spin vectors and at some level of greater complexity. The first of these cutoffs is utilized to define a termination to a sequence. The second, which is a practical limit to what can be programmed, requires a random input at each instruction which would normally require appeal to a more complex level.

The foregoing model resembles a hidden-variable theory in its approach, but it differs from the usual idea of a hidden-variable theory in that the background is not a totally unanalyzed abstract mathematical structure. Indeed, my aim is to begin to construct a testable mechanism for the background. This program requires that the background should not be totally hidden. Although the *state* of the background is, in any given experiment, essentially inaccessible to observation, the *nature* of the background must be capable of progressive investigation.

Any theory which is of the hidden-variable type (as is mine) must meet the formal mathematical difficulties which the hidden-variable theories encounter. I shall try to show that the difficulties are due to the assumption that if a mechanism is capable of forming a background then it is a classical mechanism. By contrast, I insist that one should be entirely open as to the nature of such mechanisms, not even presupposing that mechanisms are classical until the contrary is proven.

The difficulties of hidden-variable theories are

(1) That it is of the essence of a hidden-variable theory that it should be possible to specify the hidden variables, so as to give in a deterministic form the complete state of a particle. However, we know that this is impossible.

(2) Any hidden-variable theory of the familiar kind will

> localize the hidden variables, and so, by Bell's argument, produce a result different from quantum-mechanical prediction.

These difficulties are avoided in the present model as follows.

(i) I do not attach hidden variables to a single particle in isolation from the rest of the universe and from the apparatus. (Nor for that matter are they attached merely to the apparatus, which would pose other difficulties.) I accept the quantum-mechanical insight that particle and apparatus must be viewed as a single complex system.

(ii) The interactions within this whole system are not to be thought of as bound, *a priori*, by space and time. Space and time are particular aspects of the experimental situation, to be defined operationally, and approximated to in the model, in each case.

IV. HOMEOSTATIC MODEL TO TAKE THE FIRST STEP TO DEFINING A CONVENTION SPACE.

In the model developed so far there are no lengths. Our general principle for introducing such a concept which is normally defined in the context of a continuum is that it has to be introduced explicitly point by point so that there is at any time only a finite number of points defined, and progressive detail in description can only be produced by increasing the number of points.[c] Also, one can only define a point in terms of an interaction process. Since we have so far only contemplated the existence of one interaction process, our next step must be to define two with an interaction between them. The method I use to take this first step—using homeostasis—is the simplest I can imagine. Indeed, this whole paper should be seen as an attempt to exhibit the steps necessary if one is to become independent of intuitive ideas of space and time, rather than as providing any definitive theory.

I shall apply the general point of view on quantum physics which has been presented in this paper to the particular experimental situation that is used to present the Einstein-Podolsky-Rosen paradox (henceforward "EPR" paradox). The usefulness of the EPR experiment is that in the standard quantum-theoretical description of the phenomenon that is used to state the paradox, probabilities appear as an essential feature and in a fairly simple mathematical context. The

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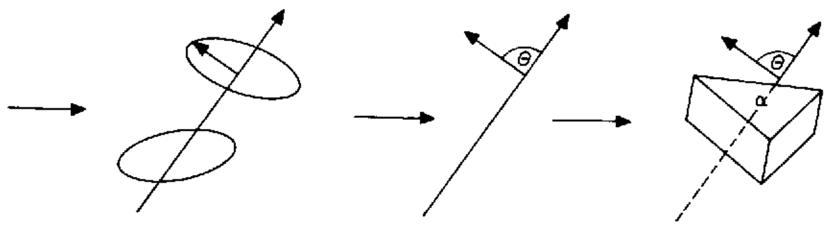
[c] A presentation of high energy physics using a concept of space which is defined in terms of particle number is being developed by Noyes[5] and is briefly described in Sec. V.

EPR experiment can be considered as a combination of the Stern-Gerlach type analyses in each of which the probability of transmission of a particle is a function of the macroscopically measured angle θ made between the preparing and the detecting polarimeters. Thus



in this idealization a spin-½ particle is considered and there is no need to consider the nature of the preparation of the particle or of the polarizer so long as they represent the essential conceptual elements of the process we are taking as a paradigm of the connection between the microsystem and the classical background or "embedding system" of macroscopic apparatus. The basic relation connecting the probability of particle detection with θ is

$$P = \cos^2 \tfrac{1}{2}\theta$$

and here the squared function derives from the quantum-theoretical relation between probabilities and wave functions and the factor ½ in the argument of the function derives from the half-integral spin. For the present purpose it is only necessary to stress that a spin state given in terms of the first polarizer, $|\uparrow\rangle$ say, has to be represented via the states defined for the second polarizer ($|\uparrow'\rangle$ and $|\downarrow'\rangle$) as a function of θ (in fact of $\tfrac{1}{2}\theta$). For example in a treatment by Wigner

$$|\uparrow\rangle = \cos \tfrac{1}{2}\theta|\uparrow'\rangle + i \sin \tfrac{1}{2}\theta|\downarrow'\rangle.$$

The essential point to stress in this treatment is that from an operational point of view quantities like $\cos \tfrac{1}{2}\theta|\uparrow\rangle$ are unanalyzable, even though conceptually they separate into a part (the operator) which specifies the macroscopic setting for the experiment and a part (the ket vector) which specifies the object system. The operational unanalyzability of this quantity also carries with it the probabilistic behavior of the object system, which therefore must play the part in standard quantum theory ascribed to it in current quantum theory and stressed recently by von Weizsäcker.[6] The spin treatment is thus a clear case of the irreducible inherence of probability in the initial quantum-theoretical concepts—a very different view from the one that must follow if my model has any reality.

The classical view of the place of probability in physics whose retention is necessary if my model is to make sense, was a major motivation for discussion of "hidden variables." There is an ideal and general impetus behind the desire to find hidden variables. One would like to have a background of interactions of some imaginable sort which by some collaborative process reproduces the appearance of discreteness which characterizes the quantum-theoretical formalism and causes us to understand why that formalism works. I am here taking the position, for which there is now some backing in the literature (see for example Ref. 7), that the quantum formalism is more a successful algorithm than a full comprehensible theory since no one has any idea of how the elementary "observation" or "measurement" process works unless they are prepared to relegate the whole of the difficulty into some portmanteau expression like "collapse of the wave function" or unless they embrace a philosophy which makes a virtue of the apparent necessity of an incomprehensible step, as does complementarity.

It is suggested that the correlation of ½ spin directions is a homeostatic phenomenon in the sense of Ashby[8] in which a condition of stability is established to a certain degree by providing a random input when the stability obtains. Homeostasis is a crude notion in a way, but on the other hand, the concatenation of hidden variables that produces the stability of the quantized state must be capable of overriding a great variety of particular conditions and must in the same sense be rather crude.

Two engines will be said to be *in the same state* when they have the same value for whichever of their parameters represent the spin state. For example, if the combinatoric scheme for representing spin suggested by the writer[7] is used, then the two ½-spin states are achieved in the engine by obliterating one or other of the elements

$$\begin{pmatrix} 0 \\ 1 \end{pmatrix}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

from the store at the two-component level. The instructions for representing the correlation state by homeostasis then conclude:

(1) If the two engines are in the same state at the randomization point (i.e., where appeal is made to a nonexistent higher level) then the state of that engine reverts to the state from which it started when the previous termination took place.
(2) If the engines are in a different state, then the input is randomized.

The program outline given above represents an idealization of the way the rest of the universe acts as a "random input" when we cut out a particular part for examination. We treat it as random when we know nothing about it as yet. This paper could be seen as an answer to the question "If there are no preconditions upon the nature of the background mechanism, and if it cannot be isolated from the rest of the universe, how can we know anything about it?"

I suggest that the only way is by progressively extending the system which we are able to discuss, attempting with each step to establish as much as possible by rigorously operational means. Probably the complexity of the world is such that it is only in very special circumstances that one attains a complete description up to the classical level. (For example, one would require a quite different use of the "engine," with quite different conditions upon it, to approximate to a particle moving in a classical path, and this is only surprising because we are in the habit of lumping all our models together because they all go on "in the world." Actually, the operational requirements to get a classical path out of an experiment like the EPR experiment, would make it something entirely different.)

Further specification of macroscopic concepts has to be provided by increasing the number of interacting particles and therefore by establishing further correlations between "engines" or computing units along the lines described for spin correlation in this section. Table I gives a guide as to how the progressive identification of macroscopic concepts might proceed.

A natural criticism of such a program might be that in such experimental operations as polarizing particle beams, one is already using magnetic fields and so on, and therefore any progressive operational specification can only be circular. This objection has a plausibility derived from our normal ways of thinking but has no real force. It is quite easy to imagine that our experimental operations with particles could be pursued using quite different sets of terms, yet getting the same results.

V. CAN A MODEL OF DISCRETE PROCESSES BE INCORPORATED INTO CURRENT PHYSICS?

So far I have discussed the logical possibility of a model based, in the way described above, on discrete processes. The question the physicist must ask is can any such model be taken seriously, given what we know of the experimental successes of the current theory, which seem to most people to require that the formalism be taken over basically unchanged, whatever interpretation be given to that formalism at the simplest stages.

Table I. Stages in the specification of basic dynamical concepts using particle observations.

Number of interacting particles	Number of interactions providing constraints on what properties the particles can have	Description
1		A particle is conventionally assumed to exist.
2	1	Velocity assumed constant till more is known.
3	2	Velocity known, acceleration conventionally assumed constant in direction and magnitude and spoken of as in one plane until known to be otherwise.
4	3	Acceleration known to be not in one line, i.e., requiring a plane (or known to be in one line as a special case). Monopolar force field description adequate.
5	4	Acceleration known to be not in one plane (except as a special case). Dipolar (electromagnetic) field description essential.
6	5	No language appropriate to particle behavior of this complexity yet developed.

What has happened in this paper has been the introduction of *analogs* of physical concepts which have the properties of the conventional concepts just so far as the discrete mathematics is able to define those properties. In other words (a) the two sets of concepts should agree completely so far as they are comparable and (b) all the properties in each of the discrete concepts should be represented in the corresponding conventional concept. However, there will be properties in the latter which will not appear in the former. One could say that each discrete concept is *embedded* in the corresponding conventional one. This relationship of embedding seems appropriate in a theory in which the continuum is an ideal to be thought of as the result of indefinitely prolonged interpolation of points. The main example of the construction of a physical concept in a discrete model —the case of spin correlation—is a good example of embedding. The idea seems obvious really, but I do not know of any history of it elsewhere.

We have another question to face however, even if we allow the technique of embedding. It may be doubted whether by starting with particle processes we can ever get those results that need the concept of a *field* or other independent starting point that described objects being spread out in space. To show that a possibility does exist of carrying out this program, I shall refer to work of Noyes.[5] Noyes's argument aims at a construction of a large part of physics and is therefore long and complex, but again I shall only be concerned to follow him just so far as to establish possibility as a logical matter.

Noyes requires two results from a combinatorial theory: (1) A sequence of numbers interpretable as the inverses of coupling constants of the main fields of physics (i.e., he takes over a well-known conjecture due originally to Eddington); (2) a background of interactions which take place in a sequence and which are such that the elementary particle events can be attributed to particular configurations of them. Ideally Noyes would require (3) that (1) and (2) be part of the same consistent scheme. Noyes's demands are in fact not stringent because he feels sufficiently confident of his approach to go ahead and merely postulate (1) and (2), though he was in fact stimulated by the combinatorial program described in this paper. As we have seen, it is too early to present (3) as more than a plausible conjecture. If the basis of (3) in our program were to be properly established this would strengthen Noyes's case.

The kernel of Noyes's argument is traced back by him, so far as any combinatorial approach goes, firstly to the original Yukawa interpretation[9] of exchange energy and quantum fluctuations; secondly to a reinterpretation of Yukawa due to Wick;[10] thirdly to an argument of Dyson[11] explaining how a coupling constant can arise because a particular number of particle interactions are required to establish a balance between positive and negative contributions to the energy of the assembly as more are added. This balance (which is defined in terms of the number of constituent particles) gives rise to the concept of a field. Noyes is really saying that these strands of argument combine to give a picture of the sort that led Born[12] from a study of the scattering situation to a probabilistic scheme of particle interactions. In Born's case, what had been achieved was the possibility of running the conventional deductive argument in reverse and giving operational primacy to the particle process (in which case, the conventional dynamical background could be left a bit shadowy).

Noyes is much more explicit than Born. He is consciously rejecting all physical reality except that of the particle, and he finishes up with quantization of action. Anyway, the essential point is that the quantum fluctuations in particle number must exist for Noyes, but they must also have a very different ontological status from what they have in current physics. They are capable of a good deal of flexibility in the way we actually represent them, since, at once, they are the absolutely fundamental physical reality and they are what the underlying model, whatever it is, has to provide for the edifice of later theorizing. Of course, so far as the model of the paper has validity, they are described by the operations existing within that model, and what we know of the appearance of probability in the quantum fluctuations (and therefore in the universe) is what we have had to postulate to make the model work.

VI. TIME

The place of length in this model has been discussed, that of time is however quite different. Within my model of one quantum process (Sec. III) one could say that events take place in a time which is defined for that process alone. To say that is, however, to say no more than that these events define a sequence and that that sequence is available to define time. Since, however, these events are not observable (the whole system is required to define one interaction), any such time is not comparable with physical time and one asks whether whatever method is adopted to define a physical time will allow sufficient flexibility for the phenomena of precognition to be fitted in. Only a general remark can be made: It seems that there will be all too much freedom and that on the contrary the difficulty will be to establish enough consistency to define a time which is applicable to macroscopic events at all. The problem seems to be that we have no assurance that if a time were defined in terms of one process which would define an order for other processes, then this ordering would remain invariant if some other process were added to the description.

These thoughts lead to a note of conjecture, on which I conclude. It seems possible that the events which give rise to what we call precognition exist in normal sequence in a time defined by some quantum process but not that which happens to be effective macroscopically. These two times are incompatible.

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DISCUSSION

WHITEMAN: There is one point that troubles me rather greatly about this paper, although the ideas have been worked out impressively. I think I am correct in saying that the paper is based on the concept of an observed particle.

BASTIN: Yes.

WHITEMAN: There are two distinct concepts of a "particle" in quantum field theory. According to one, by a "particle" we mean the orthonormal component of a field. We split the field into orthonormal components, and one of the components counted once over is called a particle.

The other concept is that of a source or sink, which we might describe as a region of coming and going of components in the field. Among sources we can include sources of interaction, which is the coming and going of quanta, that is, orthonormal components, between one field and another.

If we are to proceed on the basis of quantum field theory, how is a particle observed? The orthonormal components generally spread over all space, and are of course unobservable directly. In quantum field theory, when we say a particle is observed I think we mean that we have a quantum interchange between the field and a source or sink, which results in the emission of a light wave or other radiation which can be recorded. There is therefore not really a particle in any normal or classical sense. So I would like to ask the question, is quantum field theory to be overthrown, and are we going back to elementary quantum mechanics?

BASTIN: I know that my answer poses difficulties. But if there are deep logical troubles, as I believe, in what you call elementary quantum theory, then *ipso facto* there are worse problems for quantum field theory, even without bringing in the well-known divergence difficulties. Now, I do know that anybody putting forth such a suggestion, or looking at the subject in this way, has got to account for certain astonishingly successful things which quantum field theory has done. Nevertheless, I regard it as a theory for certain particular purposes; not as having very great universality; and certainly not as being likely to get us very far if we want to consider the wider universe in which parapsychology work operates.

WALKER: I was rather interested and pleased about the idea of the engine that runs all this. Maybe the engine is hidden variables, and thinking of that engine and machine—perhaps we have a machine in the ghost, instead of a ghost in the machine.

But I also want to rush to the defense of all those poor soldiers, the parapsychologists, who have for years been laboring away to study the distance effect, and time effects, as far as the paranormal phenomena are concerned. I do not think it is quite justified to say that, since there has not been an inverse distance law, some kind of distance dependence discovered, that nothing, no law, has been discovered there. Rather what has been discovered is a very essential and unique characteristic: psi phenomena are independent of spatial and temporal separation. To my knowledge such a characteristic occurs only in one place in physics, in only one part of the physics literature. It occurs only where the measurement problem is discussed. It is here that Bell derives the particular characteristic that hidden variables would have to satisfy, if they are to be introduced into quantum mechanics, to bring about or be associated with the reduction of the state vector. It is required that they be nonlocal, or independent of the spatial and temporal coordinates separating the two systems in which the measurements are carried out, independent of the space and time separating the two components of the original molecule in the Einstein, Podolsky, and Rosen experiment.

That being the case, I think that one should take very seriously the possibility that what quantum mechanics in its disturbing form is telling us is that quantum mechanics is incomplete; and alas, we have precisely the characteristics, waving a red flag in front of us, that we desire to introduce here. It is in the literature already.

BASTIN: Oh yes. You could call this a hidden variable point of view. Only I rushed in where angels fear to tread and actually suggested what some of these hidden variables might be doing. There are other slightly sophisticated points where this is not straightforwardly a hidden variable theory in the normal sense. And of course, it is as nonlocal as it could be.

I actually agree with your other point too. I think it is profoundly important to find out what can be known about space-time dependence and I was only making the point that physics requires a very specific kind of space-time dependence, and if you do not find it sitting on the surface, the safest thing to do would be to assume it is not there, and construct some sort of model which starts from the assumption that it is not there.

FEINBERG: I would like to make several comments, mainly applicable to the discussion which went on before Dr. Walker spoke.

First, it is quite reasonable to regard quantum field theory as a complicated way of describing particles. That is to say, the quantum fields are not, so to speak, the fundamental quantities, rather the particles are, and the fields are a particular mathematical way of talking about them. Indeed, most current textbooks on the subject take this point of view.

The second comment is that, I think perhaps Dr. Bastin is using the word "particle" in a slightly metaphorical sense. The particles dealt with in contemporary physics typically do not have sharply defined positions, for example. They are not point particles, in the sense of Newtonian mechanics. They are rather things with definite values of certain quantities, like charge, mass, and so on, and there is therefore no particular contradiction between having these particles and having the continuous variables that one deals with in quantum field theory.

The third comment is that physics is rather richer than some of us give it credit for being. Several comments have been made that if you do not find a decrease of parapsychological effects with distance, it shows that somehow they are not in line with the rest of physics. However, a perusal of any number of papers in the *Physical Review* and other journals over the last year will indicate that several physicists have been pursuing the question of forces which increase rather than decrease with distance. They have been led to this, not by studying parapsychology, but rather by studying certain properties of elementary particles which seem to indicate that the elementary forces between these elementary particles are distance-increasing rather than distance-decreasing.

Now, I bring this up not because I think that these particular things have anything to do with parapsychology, but just to reinforce what I said earlier, that contemporary physics is a rather rich subject. One should be very wary, unless one makes a fairly detailed study of it, before saying that such and such a thing is in contradiction with what physicists know or what physicists are trying to do. It is a rather dangerous thing to do, and I think that one may live to eat one's words, if one makes that kind of statement.

FIRSOFF: I wanted to make one fairly trivial observation, about the Nautical Almanac or chronological time. Let us suppose a black hole ventured near the solar system. That would alter the general gravitational field in our vicinity and so change the velocity of light and the time metric. But the predictions made in the Nautical Almanac will still hold. An eclipse will still follow the predictions—as observed by us but not by an outside observer.

BASTIN: We should be torn to pieces, but . . .

FIRSOFF: Oh, no, it will depend on how close the black hole has come to us. It will alter the general field around us, and so the velocity of light will change. Therefore the time metric will change, because it is based on the velocity of light. But it will not affect the predictions made in the Nautical Almanac, because the two factors will alter, *pari passu,* canceling each other.

But an outside observer, looking at us from another star system, will not find it so. To him, of course, the Nautical Almanac's predictions will not work, because the metric of time which he has copied from the Nautical Almanac will not correspond with his observations.

This by itself is perhaps not very important as such, but it has further possibilities, because time is not fixed; for instance, biological or psychological time is not clearly related to the astronomical or chronological time. We may assume therefore that there is a parapsychological time which runs still at a different rate, and then you will get all sorts of funny time reversals.

It is a very loose thought, but it is based on this physical fact or generally acknowledged point which I made at first.

BASTIN: Would you actually get inconsistent time orders? Or would they perhaps be incomparable? Would you get a crossing over; that is, an *ABC* situation going into an *ACB* situation?

FIRSOFF: Well, that would be time shift, as I mentioned in my Edinburgh paper, that if we had a time signal traveling faster than light and we obtained some information about what was happening in the Andromeda Nebula by means of that signal, we might have to wait a million years before it could be observed.

BASTIN: But you are not in the context of normal relativity or black hole theory now?

FIRSOFF: No, that is more or less outside.

BEAUREGARD: I am disturbed with what you are saying about changing the velocity of light. Is it not true that in any point instant of a Riemannian manifold, there is a Minkowskian tangent space-time?

Therefore any laboratory measurement will yield the velocity of light as we know it today. So perhaps you are speaking of time as a coordinate in some global sense, but certainly not in the local sense as measured in laboratory experiments.

FIRSOFF: Well, it agrees with what I say, that to us on earth, the predictions of the Nautical Almanac will hold. But the observer in another star system will have a different time rate, because the velocity of light there, as measured by him, will be different. He does not need for this purpose to step outside the cosmos. And therefore the two measures will not agree. Well, it is well known, in the case of black holes, that time stands still for the observer at the Schwartzschild radius. But it does not stand still to the outside observer who is looking at the black hole, assuming he can see it from another star system.

BEAUREGARD: I am perfectly well aware of this problem, because I have been consulted by the Bureau International des Poids et Mesures for the new definition of the time standard.

FEINBERG: I would like to remark that if a black hole came near the solar system, there would be a deviation in the observation of eclipses, because the local metric would be somewhat altered. Although it is true that in measurements made over an infinitesimal region of space, there would be no change, if you compared things happening here with the sun, then there would be a difference. In fact, measurements have already been made, without the need for black holes, of the variation of the velocity of light when it passes near the sun and when it does not pass near the sun. That would also happen if a black hole happened to wander through our neighborhood.

BEAUREGARD: Yes, one must fairly distinguish between time as a coordinate, which means some sense of globality, and time as it appears in the local metric of Minkowski's space-time.

FIRSOFF: That is agreed.

WHITEMAN: I am prepared to risk eating my words by coming in defense of quantum field theory, because I feel there are many opinions current about the subject which are incompatible with its mathematical language. My motive is not to oppose fruitful research, and in this case I consider there are ideas worth following up. My interest is in securing some protection against logical confusion. We must try to keep our language clear and consistent, so as to avoid talking nonsense.

Now, there are situations where the difficulty over talking about "particles" seems to me to become acute, not only in quantum field theory, but also in elementary quantum mechanics, because we know that there are fundamental epistemological problems or paradoxes which cannot be resolved on that basis. In standard texts as well as in my papers it is shown that certain paradoxes cannot be resolved unless one admits the unlocalizability of particles in the field. Furthermore, in a system such as the hydrogen atom an electron cannot be localized, because even if one starts off with the representation of the electron as a pointlike wave packet, within a minute fraction of a second it will have spread over the whole field around the nucleus.

But it is said that greater difficulties arise in quantum field theory, and this is where I think the situation is misconceived.

First I want to say that in lecturing on the Compton effect according to quantum field theory, using the S-matrix, I find myself uplifted and thrilled. I believe it is one of the most magnificent, astonishing, and logically satisfying pieces of work in the whole of physics. If, on the other hand, I have to lecture on radiation or collision theory according to the semiclassical methods of elementary quantum mechanics, I have to grit my teeth, because all the time there are illogical shifts and inconsistencies introduced to make the answers come right, and as a mathematician and philosopher I find all this horrifying. There is always a risk, if one does not adopt quantum field theory, of falling into logical confusion.

So one of the strongest arguments for quantum field theory is that it removes the makeshifts and paradoxes. It has limitations, of course, and one can go far beyond with the help of trial classical devices. But at what expense? If we consider the solutions offered for certain problems with which quantum field theory cannot cope, such as the explanation of the periodic table, we find again a logical botch. It is the best we can do, and the agreement is impressive. But we are in effect saying, "Appeal to classical ideas here, try this classical device there, so as to get a rough fit."

Now, what about the divergences? Every physical theory, such as classical electrodynamics, is founded on divergences. The expression $1/r$ and other singularities occur unavoidably. How do we deal with such difficulties in classical electrodynamics? We have to adopt cunning limiting processes so as to short-circuit the mathematical troubles. It is a general rule that in adjusting mathematical theories to physical measurement tricky problems of logic arise and have to be resolved by some method that at first sight looks fantastic. The fact that divergences appear in quantum field theory is therefore to be expected. All we have to do is to devise an appropriate technique for overleaping them, so to speak, in such a way as to keep our thinking logically consistent.