Superpositions, Coherence and Choice:

Towards a Physics of Life*

by

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ABSTRACT

A reassessment of physics and other enjoyable orderings of our perceptions is made and the relevance of certain concepts towards a complete description of the perceived world is pointed out. The remarkable absence of a category appropriate to choice or creativity in contemporary physics is recognized. A plea is made for evolving a scientific cosmology of the entire perceived universe.

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Introduction

Physics is the ordering of our perceptions and the consequence of such ordering on the faculty of perception and the constellation of ideas that constitute our communicable universe. In as much as it deals with all our perceptions no domain of human experience is outside the domain of physics whether it be lauded as scientific or denigrated as mystical, paranormal or supernatural. As the body of our knowledge grows the depth and subtlety of physical models increase and more phenomena become subject to physics. Physics is structured by refined perceptions and the conceptual framework associated with them.

1. Time and Temporal Evolution

The fundamental concept which dominates our physics today is that of dynamics. While Galileo and Newton were concerned with motion of ponderable isolated bodies we see dynamics in its general form as the stringing together of sequences of configurations (kinematical states) labelled by a monotonically increasing parameter, identifying the configurations as being the successive states of the same system and expressing this succession in terms of definitive rules. This "stopping of the world" is what gives the notion of the abstract dynamical system; and the law of succession expressed in mathematical form are the equation of motion. For a standard dynamical system the equation of motion is stated in a manner that applies to all configurations: there is a clear separation between initial conditions and equations of motion.

Seen thus the very notion of a dynamical system implies a set of restrictions. The world is an orderly place because the configurations at different times are not freely chosen. Given an initial configuration the later configuration is not arbitrary; one specific configuration would be chosen by virtue of the equations of motion. The future holds nothing unknowable: dynamical evolution is the reexpression of the initial state unfolding in an orderly manner.

In Newtonian physics the initial configurations required were conveniently taken to be the positions and velocities of all the particles, the equations of motion expressing the accelerations as functions of the positions and velocities. Since the evolution is step-by-step in time it is possible to point to the accelerations multiplied by the masses as the forces which cause the motion. But this view of cause (force) and effect (acceleration) arise from a fragmentation of perception in seeing the system as consisting of parts: for a closed system is the cause of its own evolution.

The use of global dynamical laws like Hamilton's Principle which derives the equation of motion as a variational Euler-Lagrange equation extremising the action integral is the first step towards the recognition that dynamics can be formulated in a manner distinct from the Newtonian format. It had already been seen that for generalizing the scope of dynamics so that rigid and deformable bodies could be brought under its purview one had to deal with constraints between coordinates of particles. But the simpler of these constraints could be handled by introducing generalized coordinates which were unconstrained but in

terms of which the configurations could be fully described. But not all constraints were so "integrable". The existence of such nonintegrable constraints was a serious incompleteness to the development of canonical dynamics. It was this gap which was solved by Dirac in his theory of constrained dynamical systems. This epoch making discovery has been the major development of dynamics since the work of Lagrange and Hamilton.

2. Dynamical Evolution and Separability in Relativistic Physics

As an example of the need to revise the "obvious" preconceptions that we have about physical systems when the scope of physics is extended to new domains and new principles are incorporated let us digress to consider a technical problem: When dealing with general dynamical structures including interaction between particles in the context of the special theory of relativity new problems are encountered. Traditionally the time indicated on a clock can be used as the monotonic labelling parameter. The configurations include the specification of positions and velocities at the same time. But distant simultaniety is not relativistically invariant.

We could continue to use the clock time as the label but insist on the canonical dynamical transformations themselves to deal with this problem. Dirac had given a formulation of the essential principles of such a relativistic canonical system. This involves the use of a Lie algebra of canonical transformations associated with the relativistic transformations constituting the ten-parameter Poincaré (inhomogeneous

Lorentz) group to reflect the change of reference frames. The Hamiltonian is one of the generators of this Lie algebra corresponding to time translations. While retaining its functional form in terms of the primary variables the Hamiltonian describes different "sections" of the set of unfolding states of the many particle system. Such an implementation of the principle of relativity together with canonical description is straightforward.

There are two additional requirements that are desirable. The first one is that of separability. When a (n+1)-particle system is considered we restrict attention to those states in which the (n+1)-particle is arbitrarily far away we could expect the system to behave as an autonomous n-particle interacting system without any reference to the $(n+1)^{th}$ particle. This requirement is not as simple to implement as one would have expected but it can be precisely stated and its consequences worked out.

An investigation of systems allowable under such conditions has been carried out by a team of scientists working in Bangalore. The results are startling: For a system of three or more particles they cannot all interact with each other if manifest covariance and separability both apply. In other words "out of sight" is not "out of mind" in such systems!

3. Coherence

When physics is to be applied to sentient beings there can be no doubt that the metabolic biochemistry, nerve electrochemistry and muscular biophysics must apply standard physicochemical principles. There are however, same novel or unusual features that must be given special consideration. Coherence, noncommutativity and superposition; and spontaniety: all these are to be as much part of our theoretical framwork as chemical thermodynamics or molecular physics.

Coherence is the correlation of parts; as such it is there in classical dynamics and is often evidenced in folk dances and chorus lines. But coherence comes into its own in wave phenomena where amplitudes are relevant but physically measured quantities are quadratic in the amplitude. Thus, for example, in the propagation of light the quantity subject to the usual photometric technique is the local intensity of light, or the flux of light which is quadratic in the amplitude. But the propagation law is for the amplitude itself. For example, if we interpose a screen in the path of the light beam in which two nearby narrow parallel slits are cut, the resulting intensity pattern on a screen further downstream shows a series of bright and dark fringes: these interference fringes are equally spaced and represent a redistribution of the intensity that was to be expected in terms of the level of illumination on the slits. The width as well as the existence of fringes can be quantitatively accounted for in terms of the wave properties of light: More about this later.

But the interesting point is that the intensity and the striped fringe pattern on the screen are not fully determined y the intensity on the slits. If the illumination is from wo different sources, even though of the same exact intensities, he interference pattern would wash out and we could have a ore or less uniform distribution on the screen. We account for his by recognizing the concept of "coherence". We say that he light vibrations from different sources are not coherent ut from different parts of the same wavefront are coherent.

Coherence is a property of the system which pertains to he relation between parts of a whole which is not necessarily xplicit at each time but which can be revealed by a suitable hysical evolution. Classical photometry has no concept of oherence since in its austere simplicity it does not have a lace for that which cannot be directly measured. Classical ave optics has a concept of coherence since underlying the photo- etric intensity it has the notion of the complex wave amplitude. uantum optics continues to have this conceptual under spinning. t is not only in religion that faith in things unseen pro- ides a more complete description of reality!

Coherence, so introduced while it manifests itself in the nfluence on the unfolding of events, is not a "cause" in the ense that a force causes acceleration. Rather, it is an inherent lement in the description that reveals itself by the dynamical nfolding, in the continuing articulation and paraphrase of he state of the system according to its own natural law. In- ariably, coherence is important precisely because there are

aspects of the specification of the state of a system unknown at one stage but by no means unknowable at a different stage. The best mechanism we know of mathematical description is to introduce amplitudes and their superpositions. To these we now turn.

4. Superpositions and Noncommutativity

We are used to systems that can be specified in a precise and unambigous fashion. And the ideal of classical kinematic description is to be able to specify the system by all its attributes: to be able to "print all the news". There is nothing unknown and unknowable at that time but which becomes revealed later. Dynamical development in this picture is the movement from one configuration to another.

When one is dealing with a wave we do have the possibility of superposition. Two waves can coexist and the result is yet another wave. But the resultant is qualitatively not different from the original wave: we could "subtract" by adding an opposite amplitude. In this the notion of superposition is distinctively different from the arithmetical addition of objects. But the really important aspect of superposition comes when there is an unobservable "phase": after all, velocities add but we have no need to invoke coherence there.

A careful examination of classical physics shows that the treatment of a physical system involves two entirely distinct categories: the dynamical variables (like position, velocity,

ass etc) and the dynamical processes (like the action of boosting or accelerating a system). The former alone are ccorded substantiality: they alone are given values in pecifying the state of a system. The processes cannot have alues along with the quantities since one is the change of he other: in mathematical parlance, they do not "commute". ne acts decisively on the other. Classical physics finds his no problem since it deals entirely with quantities. As e have already mentioned in an earlier section, we may asso- iate dynamical variables with processes: energy with time volution or angular momentum with rotation. But these are ssociations, not identifications.

. Identification of Substance and Process: Quantum Theory

It is the remarkable genius of this century that this istinction between process and substance has been erased in theoretical framework which promotes the above associations o identification. The processes and quantities not commuting eans that they cannot be both specified quantitatively t the same time. Classical physics took care of this by hoosing always to give values to quantities and ignoring pro- esses: it was consistent in this denial. But the new quantum hysics decided to accord equal role to them and identify both ith the familiar dynamical variables. For example the process f displacing the position is identified with the momentum. It ollows that position and momentum cannot commute: the celebrated eisenberg uncertainty relation is one expression of the unusual orld picture that emerges.

It follows that a quantum system must always contain information that cannot be directly apprehended at any instant but which becomes available at a later stage: a true case of revelation!

It is often said that quantum physics is difficult to comprehend since it is so far from our usual classical experience and must forever remain in the language of mathematics. I find it difficult to accept this view. Our own experience of the percieved universe is that we not only perceive an outer universe but act on that perception to get newer world views. This complex of perceptions and the perception of the transmutation of perceptions is much more akin to quantum physics than classical physics. It is rarely that we are sure of the content of our awareness in a manner that we can articulate it. Anyone who can express himself fully about his total perception in ordinary language is either decieving us or decieving himself. Quantum world order is much more intuitively appealing to us than classical world order.

Very often people attempt to make use of classical world pictures and models for depicting a quantum system. In such cases inevitably distortions must emerge. This is the origin of the notorious quantum uncertainties. If we attempt to depict the spherical surface of the earth globe on flat sheets of paper in making maps, however commendable and commonsense the effort, it must result in distortions, separating regions which are geographically contiguous or distorting shapes and areas. We know that there is no fissure in the Pacific ocean separating

e Mongolian Peninsula from Alaska if the map presents them be so far apart. In the same sense the quantum uncertainties e artifacts of description devoid of fundamental significance. is noteworthy that the most relevant examples of quantum obabilistic behaviour almost always have a classical stochastic tectors like a counter in the experimental arrangement.

Beyond Cause: Creativity and Choice

The final topic that I wish to discuss is the transcedence cause: the question of spontaniety. We value such spontaniety a mark of liveliness and celebrate it as creativity. By the ture of creativity there can be no "cause" for it: we can only cilitate creativity and spontaniety, not cause it. Along with ontaniety is the volitional component of "option". It is a markable fact that neither classical nor quantum physics (and nce all the physical sciences) has a niche for options. We ve two very poor substitutes: statistical probability and ndomness. But I wish to emphasize that uncertainty or randomess is not choice. As modern biology intends to consider life may not involve options or choices; but I am aware of choices; d I guess others are. If this perception is not an illusion en some living systems contain options: and present day physics incomplete in not providing a niche for choices and to operly distinguish it from chance.

I am not suggesting for a moment that we are not to conider the possibility that causes not found may not be understandable in certain cases as the dynamical unfolding of unpreciated coherence or tendencies. But I am suggesting that

ignoring of the existence of genuine (uncaused) choices is a mutilation, a veritable bed of Procrustus.

7. Towards A Complete Cosmology

A satisfactory scientific cosmology would involve all our perceptions, be it of the very large or very small. But it would also involve the direct perceptions of the experimenter. The arbitrary exclusion of a significant segment of our experience and perceptions is unscientific. It is true that adequate care must be exercised in refining perceptions and controlling variability. But all reproducible and communicable experiences must be included within the scope of scientific investigations. State of the art instrumentation and modern mathematical techniques should warrant careful reexamination of coherence phenomena and instances of choice: of tendencies as well as emergent qualities. It is my experience and that of others that as perception is refined more extended coherence manifests and yet more creativity manifests too.

It is probably not too farfetched to suggest that "option" and "coherence" are as much essentials of life as metabolism, genetic imprinting and reproductive invariance. Rather than fall into the absurdity of ignoring phenomena until a theory can accomodate it, it may be a worth while attempt to recognize these characteristics of life in general.

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