PHILOSOPHY IN AMERICA

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XII

QUANTUM PHYSICS AND THE PHILOSOPHY OF WHITEHEAD

by ABNER SHIMONY

Associate Professor of the Philosophy of Science
Massachusetts Institute of Technology

I. INTRODUCTION

One of the virtues which Whitehead claims for his philosophy of organism is that it provides a conceptual framework for quantum theory (*SMW* chapter 8, *PR* 121–2 and 145).[1] The theory which he has in mind is the 'old' quantum theory, consisting of the hypotheses of Planck (1901) and of Einstein (1905) that electromagnetic energy is emitted and absorbed in quanta, together with Bohr's model of the atom (1913) in which discontinuous transitions were supposed to occur between discrete electronic orbits. The philosophy of organism was presented in a preliminary form in the Lowell Lectures of 1925 (published in the same year as *SMW*) and in its most systematic form in the Gifford Lectures of 1927–8 (published as *PR* in 1929). It was during the years 1924–28 that De Broglie, Schrödinger, Heisenberg, Born, Jordan, Bohr, Dirac, and others developed the 'new' quantum theory, which was more systematic than the old, much more successful in its predictions, and more revolutionary in its departures from classical physics. Whitehead never refers to the new quantum theory,[2] and it would be unreasonable to expect that even so imaginative a philosopher and scientist could have anticipated it except in the most general terms. Nevertheless, it is important in evaluating the philosophy of organism to determine how well its physical implications agree with quantum theory and with contemporary microphysical theory

[1] The abbreviations of the titles of Whitehead's works and the editions to which the page numbers refer are as follows:
SMW *Science and the Modern World* (New York: Macmillan 1925).
PR *Process and Reality* (New York: Macmillan 1929).
AI *Adventures of Ideas* (New York: Macmillan 1933).

[2] Hereafter the qualification 'new' will be omitted.

in general. To do this is the primary purpose of the present essay. It will appear that the agreement is only partial and that there are several crucial discrepancies both in detailed predictions and in general spirit.

The second purpose of this essay is to suggest the possibility of a modified philosophy of organism, which would preserve Whitehead's essential ideas while according with the discoveries of modern physics. This is a very ambitious programme, and only a few tentative speculations on how one might proceed will be presented. It is, furthermore, a somewhat hazardous programme, for one can cite many examples in the history of thought of philosophical schemes which attempted to conform to current science but succeeded only in amplifying scientific error. One can but hope that the comparison of quantum theory with a philosophical system of such great scope as Whitehead's will not only improve the philosophical system, but will throw light upon some of the conceptual difficulties in modern physics.

II. IMPLICATIONS OF THE PHILOSOPHY OF ORGANISM FOR MICROPHYSICS

In *SMW* Whitehead criticizes classical physics for supposing that there exist material entities without any intrinsic mental characteristics, and for supposing that these entities are simply located, i.e. '*here* in space and *here* in time, or *here* in space-time, in a perfectly definite sense which does not require for its explanation any reference to other regions of space-time' (*SMW* 72). Both of these suppositions, he claims, are instances of the 'fallacy of misplaced concreteness', which consists in regarding abstract characteristics of things as their complete and concrete natures. The philosophy of organism, which is an attempt to avoid misplaced concreteness, requires a radically different conception of physical reality from that of classical materialism. In this Section some propositions of 'Whiteheadian physics' (omitting relativity theory) will be listed, partly on the basis of Whitehead's explicit remarks and partly by inference. For this purpose, the following theses of the philosophy of organism are relevant.[1]

[1] Except for thesis (5), for which a special reference is given, these theses are selected from the 'categories of explanation' and 'categoreal obligations' (PR 33–41) with much condensation, rearrangement, and simplification.

(1) The ultimate concrete objects in the universe[1] are the 'actual occasions', each of which has proto-mental characteristics and can be characterized as a unit of experience. The word 'experience' is obscure, and various of Whitehead's statements have the effect of postulating that the word may be applied to entities usually considered to be inorganic, without entirely vitiating its ordinary intension.

(2) Every actual occasion is distinguishable from every other in virtue of its intrinsic character and not merely because of its external relations to the rest of the world.

(3) An actual occasion 'prehends' each occasion antecedent to it, i.e. it recognizes the experience of the antecedent occasions in qualitative detail, though with loss of immediacy and shift of emphasis. It is the relation of prehension which prevents actual occasions from being simply located (cf. *PR* 208).

(4) The temporal duration of an actual occasion is finite, and even though phases of the becoming of an occasion can be distinguished, each phase is only derivatively real and is incomplete without reference to the entire occasion.

(5) Each actual occasion occupies a definite spatial region and is indefinitely divisible, but the parts have only derivative reality relative to the whole occasion (*PR* 434–5).

(6) The total set of prehensions of antecedent occasions by an occasion in process of becoming does not suffice to determine that process in all its details. There is, thus, an element of freedom in the process, negligible in low-order occasions but permitting radical novelty in those of higher order.

The foregoing fragment of Whitehead's philosophy not only contains implicitly most of his views on physics, but also contains his explanation of the existence of the subject-matter for special sciences such as physics. Most occasions are almost entirely constituted by their prehensions of antecedent occasions, since spontaneity and originality are usually negligible. As a result, the world, or at least that part of it contained in our 'cosmic epoch', is populated largely by 'enduring objects'. An enduring object is a temporally ordered chain of actual occasions, all sharing a common defining characteristic and sharing it because it is the dominant element in the prehensions of each successive occasion in the chain. Thus the

[1] The one exception to this statement is the actual entity God, who shares some but not all of the characteristics of the actual occasions.

enduring object is, in a sense, self-sustaining. Even in a heterogeneous society of occasions there may be characteristics common to all or nearly all members, so that the prehensions of new occasions will be virtually uniform in certain respects and the common characteristics will tend to persist. Conformity to a basic law of physics is an outstanding example of a persistent set of characteristics in a heterogeneous society. Special laws, such as those of biology, may hold in sub-societies of the vast society governed by the basic physical laws. The special laws may not be derivable from the more basic laws, and yet they may presuppose the order established by the latter. Similarly, the basic laws governing a heterogeneous society determine its tolerance for various kinds of simple enduring objects, with the result that the number of species of elementary particles may be small, although the number of exemplars of each may be enormous. (Cf. *AI* 257 and 264, *PR* 138–140.)

It follows from Whitehead's view of the nature of physical laws that they cannot be derived from his philosophical first principles. In fact, since he supposes that the propagation of dominant characteristics in a society is subject to lapses, he infers that the type of order expressed by physical laws may decay or change. Nevertheless, Whitehead's philosophical principles do seem to have at least the following physical consequences, which would presumably be valid in any cosmic epoch.

(i) Even though physics abstracts from the detailed content of an actual occasion, it cannot overlook the spatial and temporal extendedness of occasions. *Hence, the most direct microphysical consequence of Whitehead's scheme is atomicity.* Thus, the physical fact that energy is transferred in quanta follows from the supposition that 'physical energy . . . must then be conceived as an abstraction from the complex energy, emotional and purposeful, inherent in the subjective form of the final synthesis in which each occasion completes itself' (*AI* 239), in conjunction with the thesis that the actual occasion is an extended atom of experience. Furthermore, there must be a temporal atomicity in physical processes, since the individual actual occasion is not divisible into concrete events, one of which is earlier than the other (*PR* 107). Whitehead seems to believe that from the fundamental atomicity of actual occasions there follow other types of physical atomicity—e.g. the integral character of elementary particles and the indivisibility of electric charge into units smaller than the charge of the electron—but he is vague on this point.[1] One would also expect him to claim that the elementary particles of physics exhibit spatial extendedness in spite of their integral character, since each occasion constituting a link in the career of a particle has an internal spatial structure. Whitehead does not make such a claim explicitly, but perhaps it is implicit in his discussion of 'vibratory organic deformations' of a proton (*SMW* 195).

(ii) *Elementary particles should be capable of creation and destruction.* According to Whitehead an elementary particle is an especially simple kind of enduring object, and the continuation of any enduring object depends upon the degree to which each new occasion in the appropriate neighbourhood will re-enact the experience of earlier occasions. Since the experience of a new occasion is partially coloured by prehensions of other occasions than those constituting the enduring object, as well as by exercise of its intrinsic spontaneity, the elementary particle will almost certainly end after a finite number of links. An inverse argument explains how an elementary particle can be initiated.

(iii) *A consequence of atomicity, according to Whitehead, is the association of some sort of vibratory motion with all elementary particles.* An elementary particle is a chain of occasions, all having nearly the same internal development, so that the particle has a definite periodic structure with a definite frequency. It is clear, however, that Whitehead conceives of waves as more generic than particles, for particles always exhibit some characteristics of waves but not conversely. Thus:

> the doctrine, here explained, conciliates Newton's corpuscular theory of light with the wave theory. For both a corpuscle, and an advancing element of wave front, are merely a permanent form propagated from atomic creature to atomic creature. A corpuscle is in fact an 'enduring object'. The notion of an 'enduring object' is, however, capable of more or less completeness of realization. Thus, in different stages of its career, a wave of light may be more or less corpuscular. A train of such waves at all stages of its career involves social order; but in the earlier stages this social order takes the more special form of loosely related strands of personal order. This dominant personal order gradually vanishes as the time advances. Its defining characteristics become less and less important, as their various features peter out. The waves then become a nexus with important social order, but with no strands of personal order. Thus the train of waves starts as a corpuscular society, and ends as a society which is not corpuscular. (*PR* 53–4)

[1] He is also careless, for example in saying that 'Electrons and protons and *photons* are unit charges of electricity' (AI 238, italics not in the original text).

(iv) *As a result of thesis* (6) *strict determinism cannot hold in physics.* However exhaustively the antecedents of a physical event are specified, the character of the event cannot, in principle, be predicted with certainty.

(v) *The specification of the state of a composite system containing several elementary particles is equivalent to the specification of the states of the individual particles.* This follows from the natural identification of the state of an elementary particle at a given time as an actual occasion, together with Whitehead's theses that actual occasions are pre-eminently real and that all groupings of occasions have derivative status.

Several further physical consequences of Whitehead's philosophy appear plausible, except for doubts regarding the extent to which physics abstracts from concreteness.

(vi) If concrete reality is considered, there is clear asymmetry between past and future, since the occasions of the past are fully determinate while those of the future are not. *It is reasonable, consequently, to expect the asymmetry between the past and the future to be exhibited in the laws of microphysics,* and not merely in macroscopic laws such as those of thermodynamics.

(vii) An occasion prehends, with suitable gradations of relevance, all previous actual occasions. *Consequently, the physical properties of an elementary particle (e.g. its charge or its magnetic moment) should be slightly modified by the inclusion of the particle in a highly organized society such as an animal body.*

(viii) If the occasions of an enduring object are considered in full concreteness, they will exhibit 'aging' from earlier to later parts of the chain, simply in virtue of the accumulation of prehensions. *Consequently, one expects a systematic development of physically observable characteristics of elementary particles*—perhaps a drift towards instability, indicative of primitive feelings of satiation, or perhaps a drift towards greater stability, indicative of the entrenchment of a habit.

III. COMPARISONS WITH CURRENT PHYSICS

Propositions (i)–(viii) will now be examined in the light of current physics. Whenever possible, these propositions will be confronted with direct experimental evidence. In most cases, however, one can do no more than compare them with their counterparts in quantum theory, so that experimental evidence can be invoked only to the extent that quantum theory as a whole is experimentally confirmed.[1]

(i) Part of Whitehead's conception of atomicity is in excellent agreement with current physics. Specifically, energy is transferred in quanta, and matter has a granular structure in the small which prevents indefinite divisibility. There is also evidence, although it is not decisive, that the integral character of an elementary particle is compatible with spatial extendedness and internal structure. Thus, experiments in which protons are scattered by protons indicate that these particles have a definite charge and current distribution, even though it is not possible to subdivide their charge into discrete parts.[2] Furthermore, it is difficult to envisage how a particle which is localized at a mathematical point could exhibit spin angular momentum; but one should be cautious in advancing this argument, since in actual calculations theoretical physicists are able to treat the spin simply as a 'quantum number' without any commitments to the extendedness or non-extendedness of the particles. With regard to temporal atomicity, which is the most radical of Whitehead's assertions concerning atomism, the

[1] Individual references will not be given for each of the propositions of quantum theory mentioned in the following discussion. Although these propositions are explained in every standard exposition of quantum theory, several books are particularly worth noting for their treatment of topics that are philosophically significant: D. Bohm, *Quantum Theory* (New York 1951), J. von Neumann, *Mathematical Foundations of Quantum Mechanics* (Princeton 1955), F. London and E. Bauer, *La Théorie de l'Observation en Mécanique Quantique* (Paris 1939), P. A. M. Dirac, *The Principles of Quantum Mechanics*, 3rd edition (Oxford 1947).

[2] Cf. R. Hofstadter, F. Bumiller, and M. R. Yearian, *Reviews of Modern Physics*, vol. 30 (1958), p. 482. The standard model for interpreting these experimental results pictures the observed proton as a 'cloud' of virtual particles, fluctuating in and out of existence. Although the cloud exhibits a statistically describable structure, the virtual particles are supposed to be 'bare' and perhaps without structure. Cf. E. M. Henley and W. Thirring, *Elementary Quantum Field Theory* (New York 1962), pp. 77–78, 219–231. This model is so different from Whitehead's conception of a spatially extended actual occasion that one must hesitate to say that the scattering experiments really support his conception.

testimony of current physics is unfavourable, but not decisively so. One of Heisenberg's uncertainty relations is $\Delta E \Delta t \sim h$, i.e. the uncertainty of the duration of a physical process can be reduced only at the price of increasing the uncertainty of the energy of the system during the process. The limitation which Heisenberg's relation places upon the sharpness of temporal specification is reminiscent of Whitehead's proposition, yet it is not the same. Whitehead is not attributing an *indeterminate* stretch of time to the actual occasion, but rather a *determinate finite* stretch; he denies temporal definiteness only to the phases within the occasion, for 'this genetic passage from phase to phase is not in physical time' (*PR* 434). Moreover, there is no hint in Whitehead's work that an occasion of short duration has a less definite energy than one of longer duration. On the contrary, he says that every actual occasion, when it has completed its process of becoming, is completely definite with respect to every family of attributes (*PR* 38, Category of Explanation xxv). It should be noted, incidentally, that although the duration of each actual occasion is indivisible, Whitehead does not assume a lower limit to the set of all durations (*SMW* 198). Nevertheless, his proposal of temporal atomicity would be supported if the postulation by March, Darling, *et al.* of a minimum length or minimum space-time region proved successful in removing the troublesome 'divergences' of quantum field theory.[1] So far their postulates have not led to outstanding successes, but in view of the great mathematical difficulties and the large number of variants to be examined their failure is not decisive.

(ii) The Whiteheadian proposition that elementary particles can be created and destroyed has been strikingly confirmed by experiments, with regard to the 'stable' as well as to the 'unstable' particles. For example, physicists have not only observed ordinary beta-decay, in which the unstable neutron decays into three stable particles, the proton, the electron, and the anti-neutrino, but they have also detected inverse beta-decay, in which a proton and an anti-neutrino are annihilated and a neutron and positron are

[1] B. T. Darling, *Physical Review*, vol. 80 (1950), p. 460, A. March, *Quantum Mechanics of Particles and Wave Fields* (New York 1951). Their postulates are motivated by the desire to eliminate the 'divergences' of quantum field theory. Because of the quantum mechanical proportionality of energy to frequency and the fact that a minimum length would imply a maximum frequency, their postulates would cut off the high range of frequencies responsible for the theoretically computed infinite energies.

created. Thus, the integral character of elementary particles is not associated with permanence, contrary to Democritean atomism but in accordance with Whiteheadian physics.

(iii) Whitehead's account of the association of waves with particles is only superficially in accord with quantum theory. The passage from pp. 53–4 of *PR*, quoted in (iii) of the preceding Section, shows that he conceives of a wave front as a set of actual occasions (a 'nexus') with each occasion occupying a small region of the front. The mutual relations among contiguous occasions, whereby they begin and end in unison, ensure that all parts of the wave front are in phase with each other. Whitehead's picture is reminiscent of Schrödinger's attempt to interpret the wave function of a particle as a description of an ordinary physical field, which manifests particle-like properties whenever the region of high field intensity is very small. This interpretation was abandoned because Schrödinger's own equation for the time dependence of the wave function implies that in the absence of confining forces an initially concentrated wave packet will disperse.[1] In order to account for the experimental fact that particles do not disperse, Born proposed that the physical content of the wave function was to determine the probabilities of experimental outcomes (e.g., $|\psi(x, y, z)|^2 dxdydz$ is the probability of finding the particle in a small volume $dxdydz$). In the Born interpretation, the wave function characterizes the state of the particle in its entirety and does not describe the physically real parts of a field. There is a sharp discrepancy between this point of view, which at present is accepted by most physicists, and Whitehead's attribution of primary reality to the occasions of a wave front.

Deeper insight into this discrepancy can be achieved by considering the following fundamental principle of quantum theory, called 'the superposition principle': if u_1, u_2, u_3, . . . represent physically possible states, then the combination $\Sigma c_i u_i$, where the c_i are arbitrary complex numbers, represents a superposition of the original states which 'overlaps' each of them in a certain sense and which, moreover, is itself a physically possible state. The nature of the 'overlap' is mostly clearly exhibited if there is an observable

[1] Cf. M. Born, *Atomic Physics* (Fifth edition, New York 1951), p. 93 and pp. 142–4, for discussion of reasons for abandoning Schrödinger's interpretation in favour of Born's and for a general discussion of attempts to rationalize wave-particle dualism.

property A of the system having definite values a_i in the states represented by the u_i, such that all the a_i are different. If the u_i are then specified as being of a standard length ('normalized' to 1), then according to quantum theory the probability of finding that $A = a_i$ when a measurement of A is performed is $|c_i|^2 / |c_1|^2 + |c_2|^2 + \ldots$. It must be insisted that $\psi = \Sigma c_i u_i$ is a maximum specification of the system; it is not a statistical description of a system which really is in a state represented by a definite, but unknown, one of the u_i. The superposition therefore has the counter-intuitive characteristic of being a state in which the observable A is objectively indefinite and not merely unknown. It follows that the uncertainty principle of Heisenberg, which limits the simultaneous determination of complementary quantities such as position and momentum, refers to the objective properties of the particle and not simply to human knowledge about these properties. The wave function $\psi(x,y,z)$ can now be understood in terms of the superposition principle: roughly, $\psi(x,y,z)$ represents a superposition of states in each of which the particle has a position localized within a small region $dxdydz$, with the numbers $\psi(x,y,z)dxdydz$ serving as the expansion coefficients in the superposition (i.e., they are the c_i in $\Sigma c_i u_i$). It should now be obvious that the quantum mechanical account of the waves associated with particles is entirely alien to the spirit of Whitehead's philosophy. In particular, the postulation of indefinite values of observable quantities, as required by the quantum mechanical account, would be repugnant to Whitehead. He might admit that indefiniteness is characteristic of the spatial or temporal parts of actual occasions, but surely not of the complete occasions, for the twenty-fifth Category of Explanation, on p. 38 of *PR*, asserts:

> The final phase in the process of concrescence, constituting an actual entity, is one complex, fully determinate feeling. . . . It is fully determinate (*a*) as to its genesis, (*b*) as to its objective character for the transcendent creativity, and (*c*) as to its prehension—positive or negative—of every item in its universe.

An important technical disagreement follows from the fundamental conceptual difference between Whitehead's analysis of wave-particle dualism and that of quantum theory. According to Whitehead, a sharp frequency may be characteristic of a well-localized particle, since the periodicity is essentially due to the reiteration of a basic pattern in successive actual occasions. In quantum theory, on the other hand, a sharp frequency is characteristic of a particle which has a definite momentum, and therefore, by the uncertainty principle, a completely indefinite position; and conversely, the wave function of a well-localized particle has a very broad spectrum of frequencies.

A final note on Whitehead's account of waves and particles is to point out a striking disconfirmation by experiment. He explicitly states, in the passage quoted above from p. 53 of *PR*, that the corpuscular character of light is gradually lost as the light is propagated—a reasonable remark given his general analysis of particles. However, the phenomenon which most vividly illustrates the particle aspect of electromagnetic radiation, the photo-electric effect, is entirely independent of the age of the radiation. In fact, photo-electric cells are attached to telescopes in order to study starlight which has travelled for millions of years.

(iv) Quantum theory and Whiteheadian physics are both indeterministic, but in quite different ways. According to quantum theory, the state of a physical system evolves in a continuous and fully deterministic manner as long as the system is isolated. Probability enters only when a measurement is made of an observable which does not have a sharp value in the state of the system prior to the measurement. The interruption of the deterministic evolution of the state does not contradict the Schrödinger equation, since a measurement requires the interaction of the system with another system—a macroscopic piece of apparatus and perhaps a conscious observer. According to Whitehead, the evolution of an isolated system (the concept of which is an idealization, since an actual occasion prehends all occasions in its past) cannot be entirely deterministic, because of the element of freedom in each occasion. If one attempts to adjudicate between these two different accounts of indeterminism by considering the success of statistical predictions, one must certainly prefer quantum theory, for its statistical predictions are remarkably good, while Whitehead's proposals are too vague to yield any quantitative statistics. Nevertheless, there may be strong reasons for exploring the hypothesis that chance events occur in isolated systems, since, as will be discussed in Section IV, the quantum theoretical account of indeterministic transitions leads to conceptual difficulties.

(v) The Whiteheadian treatment of the state of a composite system is at odds with a quantum mechanical principle which has attracted little attention in spite of its revolutionary philosophical implications: *that a several-particle system may be in a definite state, i.e. may have as definite properties as quantum theory permits, without the individual particles being in definite states.* To illustrate this principle consider two systems I and II and let $\phi_1(\mathrm{I})$ and $\phi_2(\mathrm{I})$ represent states of I in which observable A has values a_1 and a_2 respectively ($a_1 \neq a_2$), and $\psi_1(\mathrm{II})$ and $\psi_2(\mathrm{II})$ represent states of II in which observable B has values b_1 and b_2 respectively ($b_1 \neq b_2$). Let $\phi_1(\mathrm{I}) \otimes \psi_1(\mathrm{II})$ represent that state of the composite system I plus II in which system I is described by $\phi_1(\mathrm{I})$ and system II by $\psi_1(\mathrm{II})$; and let $\phi_2(\mathrm{I}) \otimes \psi_2(\mathrm{II})$ be similar. The superposition principle can now be invoked to affirm the physical possibility of a remarkable state, namely, the one represented by

$$\psi = \frac{1}{\sqrt{2}} (\phi_1(\mathrm{I}) \otimes \psi_1(\mathrm{II})) + \frac{1}{\sqrt{\ }} (\phi_2(\mathrm{I}) \otimes \Psi_2(\mathrm{II})) .$$

Neither I nor II is in a definite state when ψ represents the state of I plus II. A rigorous proof will be omitted, but the following rough argument indicates the essential reason: if one tries to claim that I is to some extent described by ϕ_1, and to some extent by ϕ_2, the claim is vague unless the expansion coefficients of ϕ_1 and ϕ_2 are specified, but in the above expression for ψ it is clear that the expansion coefficients refer to states of II. One might try to reconcile the existence of such states of several-particle systems with Whitehead's consequence (v) by identifying the state of a several-particle system with a single actual occasion, and identifying the individual particles at a given moment with subdivisions of the occasion. Divisions of an occasion could be reasonably expected to lack the specificity implied in saying that an entity is in a definite state, for 'in dividing the region we are ignoring the subjective unity which is inconsistent with such divisions' (*PR* 435). This attempt at reconciliation fails, however, because quantum mechanics permits the parts of a system described by ψ to be indefinitely far apart spatially.[1] An actual occasion which not only is macroscopically extended, but even broken into non-contiguous parts, is evidently contrary to Whitehead. To be sure, he is reticent about the exact extent of an occasion, but he seems to fear that the

[1] Cf. D. Bohm and Y. Aharonov, *Physical Review*, vol. 108 (1957), p. 1070.

identification of a large scale process as a single occasion will remove the barriers to Spinozistic monism (cf. *PR* 10–11).

It is appropriate at this point to interpolate a discussion of another quantum mechanical principle concerning several-particle systems, even though it has no clear counterpart in Whiteheadian physics: *that if a system contains several elementary particles of the same species, they must all play the same role in the system as a whole.* Consider, for example, a system composed of two pi-mesons, and suppose ϕ_1 and ϕ_2 each represents a possible state of a single pi-meson. Then the principle forbids the composite system to be in the state represented by $\phi_1 \otimes \phi_2$, for in this state pi-mesons I and II have different roles; but the principle permits the state represented by

$$\frac{1}{\sqrt{2}}\,(\phi_1(\mathrm{I}) \otimes \phi_2(\mathrm{II})) + \frac{1}{\sqrt{2}}\,(\phi_2(\mathrm{I}) \otimes \phi_1(\mathrm{II})),$$

for this state is 'symmetrized' with respect to the two particles.[1]

To fit symmetrization into the framework of Whiteheadian physics is a delicate matter, since it implies a kind of loss of identity of the individual particles. In particular, the simple model of particle I as a chain of occasions $O_1, O_1', O_1'', \ldots$ and of particle II as a chain $O_2, O_2', O_2'', \ldots$ will not work, because individual occasions are always distinguishable in virtue of intrinsic characteristics (thesis 2 of Sect. II) and hence the two chains are distinguishable. A possible reply is that physics does not treat actual occasions *in concreto* and hence can fail to take cognizance of the respect in which the chains $O_1, O_1', O_1'', \ldots$ and $O_2, O_2', O_2'', \ldots$ are different; but the symmetrization obtained in this manner would appear to be a coincidence rather than a general law.

A more promising explanation is that the chains $O_1, O_1', O_1'', \ldots$ and $O_2, O_2', O_2'', \ldots$ intersect and the occasions which are shared by several chains have a quite different character—the physical manifestation of which is symmetrization—from the character of the occasions prior to the merger of the chains or after their separation. This explanation conforms to Whitehead's

[1] Symmetrization is actually a property of states of systems composed of particles with 'integral spin'. When the particles have 'half-integer spin', as do electrons, neutrinos, neutrons, and protons, the state of the composite system must be 'anti-symmetrized'. However, the difference between symmetrization and anti-symmetrization is irrelevant for the present purpose, which is to insist upon the identity of roles of all particles of the same species.

general view that the corpuscular nature of a variety of occasions is highly special and easily dissipated. However, the explanation encounters the same difficulty that was noticed in the preceding paragraph. Composite systems containing particles of the same species can have indefinitely large spatial extent, as in the case of the conduction electrons in a bar of metal. Since all the particles play the same role, it becomes necessary to identify the state of a macroscopically extended system with a single actual occasion, contrary to Whitehead's conception of the actual occasion as a microscopic entity.

(vi) In contemporary physics the only laws which involve a definite direction of time are macroscopic, the outstanding one being the thermodynamic law of entropy increase. No microphysical law has yet been discovered which is not invariant under reversal of the direction of time. If this peculiarity remains a permanent feature of physics, it would constitute evidence detrimental to Whitehead's scheme, in which the asymmetry of past and future is essential.The only defence of a Whiteheadian physics would then be the desperate one that the asymmetry of past and future is one of the features of concrete reality neglected by physics. However, since the discovery of parity non-conservation by Yang and Lee *et al.*, the confidence of physicists in some of the physical symmetry principles has been shaken, and many suspect that a violation of time-reversal invariance will also be detected.[1]

(viii) The Whiteheadian expectation that the physical properties of an elementary particle are slightly modified when the particle enters a structural society is counter to the reductionist spirit of physics, chemistry, and biophysics. Many of the predictions of these sciences rest upon the assumption that such properties of elementary particles as charge, mass, and magnetic moment are unchanged by the incorporation of the particles into highly structured macroscopic objects. Of course, the same predictions would be made if the changes due to incorporation are extremely small. Since Whitehead gives no indication of the amount of modification to be expected there can be no crucial experiment.

(viii) The 'aging' of elementary particles implied by Whitehead's philosophy is contrary to current physical theory and is not confirmed by experiment. The intrinsic properties of newly

[1] Cf. P. Morrison, *American Journal of Physics*, vol. 26 (1958), p. 358.

created elementary particles seem to be no different, at least statistically, from those of particles which have endured a long while. Particularly significant is the decay rate in a population of unstable particles. The number of neutrons, for example, decaying per unit time is proportional to the number of neutrons in the population (with allowance, of course, for statistical fluctuations), and is independent of the 'age' of the population. It is reasonable to infer that the probability that a given neutron will decay during an interval of time is independent of the age of the neutron, thus suggesting that no physically significant changes occur in the neutron due to aging. Again, however, Whitehead's statements permit no quantitative estimate of the change to be anticipated in the decay rate, and therefore no crucial experiment is possible.

IV. PROPOSALS FOR RECONSTRUCTION

The discrepancies noted in Sect. III between Whiteheadian physics and current microphysics constitute strong disconfirmation of Whitehead's philosophy as a whole. The possibility remains, however, of constructing a philosophical system, Whiteheadian in its general conceptions though not in details, and according with the fundamental discoveries of science. A few tentative suggestions will be given here concerning the initiation of such a large philosophical undertaking.

A useful first step is to distinguish both in the philosophy of organism and in quantum theory those elements which are radical by the standards of classical physics from those which are conservative. Most radical in Whitehead's philosophy are the attribution of proto-mental properties to entities normally considered to be physical, and the postulation of prehension as the fundamental relation between occasions. The assumption of the complete definiteness of the occasion in its final stage is conservative, although the correlative assumption of indefiniteness in the early stages of concrescence is not. Also conservative is his reductionist assumption that the characteristics of a nexus are entirely determined by the characteristics of its constituent occasions. Quantum theory is conservative in supposing that certain quantities initially introduced in the study of macroscopic physical objects—especially spatio-temporal position, energy, momentum, angular momentum, charge, and magnetic moment—can be used meaningfully in characterizing microscopic entities. On the other hand, the superposition principle is radical, for it has the consequence that a physical quantity can have an indefinite value in a maximally specific state of a microscopic system and has a sharp value only in exceptional states (the 'eigenstates' of that quantity). Quantum theory is also radical in its treatment of the relation between the state of a several-particle system and the states of its constituent particles.

The foregoing juxtaposition suggests a programme of reconstruction: *to graft the radical elements of quantum theory onto the radical elements of the philosophy of organism, by assuming that elementary entities have proto-mental characteristics while treating the states of these entities in accordance with the combinatory principles of quantum theory*. The synthesis contemplated here does not seem forced from a Whiteheadian point of view. Whitehead often engages in a dialectical analysis which is reminiscent of the quantum mechanical treatment of complementary quantities,[1] but he never achieves what is most remarkable in quantum theory—a set of systematic rules for predicting statistically what will appear when a shift is made from one description to a complementary one. A modification of Whitehead's philosophy in accordance with the combinatory principles of quantum theory would perhaps make explicit and precise certain tendencies that are implicit and haphazard in his work.

Such a modification of Whitehead's system would surely change the conception of an actual occasion. For example, it would be impossible to maintain that an actual occasion, in its final phase, is definite with respect to every family of attributes (*PR* 38, Category of Explanation xxv). Instead, in accordance with the uncertainty principle, the specificity of any attribute is always attained at the price of indefiniteness of other attributes. In particular, an occasion may have a quite sharp location in time and an arbitrarily short duration, provided that properties complementary to duration are

[1] This is most striking in Whitehead's theology: 'It is as true to say that God is permanent and the World fluent, as that the World is permanent and God is fluent. . . .' (PR 528). Whitehead explains that 'In each antithesis there is a shift of meaning which converts the opposition into a contrast' (*ibid.*). Dialectical analysis is also exhibited in the more mundane parts of his philosophy, for example in his statements that an actual occasion is prehended in its concreteness and yet with loss of immediacy.

sufficiently indefinite.[1] It is also possible that the actual occasions may lose their status of being (along with God) the only ultimate real entities, and they may appear instead only as special cases of ultimate reality. Elementary particle theory and quantum electrodynamics may provide a hint as to the more general form of ultimate reality: i.e., it might be some kind of 'field' of diffused primitive feeling, of which the actual occasions are 'quanta' existing whenever there are individual loci of feeling. The hypothesis of diffused feelings is no more of an extrapolation from psychological data than is Whitehead's attribution of proto-mental characteristics to elementary particles, and indeed our everyday experience of sensitivity pervading the whole human body may possibly be construed as confirmation of the hypothesis.

The physical evidence concerning composite systems, discussed in (v) of Sect. III, suggests a quantum-theoretical refinement of Whitehead's treatment of the relation between the nexus and its constituent occasions. Whitehead conceives of the nexus in a reductionist manner, as the totality of its constituent occasions, and he supposes the internal relations exhibited in a nexus to be completely explicable in terms of the prehensions of earlier occasions of the nexus by each new occasion. Quantum theory, on the other hand, treats a composite system in a subtle manner, which at first seems paradoxical: it allows the state of the composite system to be described, in a certain sense, in terms of its components, and yet it permits the composite system to be in a definite state even when its components are not. This treatment, of course, is intimately bound up with the superposition principle. Thus, in the example cited in the previous Section, the composite system I plus II is in the state represented by

$$\Psi = \frac{1}{\sqrt{2}}(\phi_1(\mathrm{I}) \otimes \psi_1(\mathrm{II})) + \frac{1}{\sqrt{2}}(\phi_2(\mathrm{I}) \otimes \psi_2(\mathrm{II})),$$

which is clearly describable in terms of the states ϕ_1 and ϕ_2 of component I and ψ_1 and ψ_2 of component II; yet, because of the character of the superposition, neither I nor II is in a definite state. If this quantum theoretical treatment of the whole-part relationship is introduced into the philosophy of organism, it

[1] According to the Heisenberg relation $\Delta E \Delta t \sim h$, the property complementary to duration is energy. But if Whitehead's thesis is maintained that physical energy is an abstraction from emotional and purposive energy (AI 239), then Heisenberg's relation may require supplementation.

opens a number of possible lines of exploration. For example, the 'field of feeling', the existence of which was hypothesized in the preceding paragraph, might be characterized holistically as being in a definite state. This state could always be described as a superposition of field states, in each of which there is a definite set of actual occasions, just as in quantum electrodynamics the state of the entire electromagnetic field can be described as a superposition of field states in each of which there is a definite set of photons. Moreover, special states of the 'field of feeling' can exist in which the superposition is in part reduced, so that definite actual occasions exist. Consequently, the existence of many independent loci of feeling, which is an essential aspect of the experienced plurality of the world, is permitted—though not required—in this modified Whiteheadian scheme. A nexus of the type described by Whitehead is also permitted but is a rather special case: it occurs when there is a network of occasions sharing some common characteristic, each in a definite single-quantum state. What the modified scheme permits which Whitehead's does not is the existence of a composite system more complex than a nexus: an '*n*-quanta system' in which each of the *n* occasions is so correlated with the others, *via* the superposition principle, that none is in a definite single-quantum state.

An evident advantage of the quantum-theoretical modification of the philosophy of organism is that it removes some of the discrepancies with modern physics noted in Sect. III—a virtue which is not surprising, since the modification was inspired by these discrepancies. A further advantage is a possible improvement in treating the question of 'simple location'. Whitehead's rejection of simple location in *SMW* is a dramatic criticism of classical physics, but his sketch of an alternative in *PR* is somewhat disappointing. His alternative is essentially to postulate the relation of prehension, whereby an actual occasion is felt in complete detail in the initial phase of each later occasion. Even if the ambiguities inherent in the conception of prehension can be dispelled, the relation of prehension can at best provide a kind of multiple location in time, i.e. the occasion as 'subject' and the same occasion as 'ingredient' in later subjects. By contrast, the quantum-theoretical modification exhibits a breakdown in simple location in space in two respects: first, the quantum state of an individual occasion may be such that its position is indefinite; and, secondly, a composite system can have spatially separated components which are not in definite states, but which are so correlated with each other that the composite system is in a definite state. Finally, there is an advantage which was briefly mentioned earlier but which deserves amplification: the possibility that the modification of Whitehead's philosophy will greatly improve the account of high-order mental phenomena—which, after all, are the only mental phenomena we know about without resorting to radical hypotheses and extrapolations. Because Whitehead conceives actual occasions to be microscopic in size, and because the human personality at any moment has a unity which entitles it to the status of an actual occasion, he is led to the strange doctrine of a microscopic locus of high-order experience wandering through the society of occasions that compose the brain:

> Thus in an animal body the presiding occasion, if there be one, is the final node, or intersection, of a complex structure of many enduring objects. . . . There is also an enduring object formed by the inheritance from presiding occasion to presiding occasion. This endurance of the mind is only one more example of the general principle on which the body is constructed. This route of presiding occasions probably wanders from part to part of the brain, dissociated from the physical material atoms. (*PR* 166–7)

The question of the location of mentality is extremely complicated, but introspection seems to indicate that it is diffused throughout the body, and neuro-physiology has not yielded evidence of extreme localization. Various of the concepts of the modified Whiteheadian scheme seem relevant in describing high-order mentality: the concept of an indefinitely located actual occasion, the concept of a field of feeling which is generally diffused but occasionally quantized, and the concept of quantum correlations among the components of a composite system. Which one of these, or which combination of them, will be most fruitful is a matter of speculation, but all of them seem preferable to Whitehead's microscopic localization of high-order mentality.[1]

This list of advantages must be weighed against some strong reservations. The first concerns a particular proposal made above

[1] Some speculations on the application of quantum theoretical concepts to mentality are given in D. Bohm, *Quantum Theory*, pp. 168–172.

rather than the general programme of a quantum-theoretical modification of the philosophy of organism. The proposal was to consider the entire 'field of feeling' as being in a definite state and to consider actual occasions as quanta of this field. One may wonder, in view of the notorious difficulties of quantum field theories, whether they are suitable models for a metaphysical scheme describing all of reality, and one may wonder whether a single field suffices for this purpose. Setting aside these doubts, however, one may still be sceptical about the adequacy of this proposal to account for the experienced plurality of the world. It was noted that the existence of a definite state of the entire field is permissive of individual loci of feeling, but is permissiveness sufficient? Is it a mere contingency, characteristic perhaps of our cosmic epoch, that there are definite actual occasions, or are there deep-lying reasons why this should always be so? Merely raising these questions exhibits the vagueness of the proposal and its need for supplementation.

A second reservation arises from the apparent absence of any clear psychological manifestations of the superposition principle, which one would expect if the combinatory principles of quantum theory apply to actual occasions. There are, to be sure, psychological phenomena which at first sight could be construed as evidence of the superposing of mental states—e.g., perceptual vagueness, emotional ambiguity, conflict of loyalties, and the symbolism of dreams. Yet in all these cases the quantitative characteristics of the superposition principle, as it is exhibited in physics, are missing.[1] This reservation, however, is not decisive, for one can optimistically reply that the absence of confirming evidence is not equivalent to the presence of disconfirming evidence. It is possible that the psychological manifestations of the superposition principle are too delicate to be detected by the introspective, behaviouristic, and physiological techniques in current use.[2] It is also possible that these techniques are sufficient, but that no one has yet been sufficiently serious about using the superposition principle in psychology to design a good experiment.

[1] This point is discussed in A. Shimony, *American Journal of Physics*, vol. 31 (1963), p. 755.

[2] Dr Karl Kornacker pointed out in a private communication that the interference effects characteristic of superpositions are no more to be expected in gross emotional and perceptual phenomena than in macroscopic physical phenomena.

A third reservation is that quantum theory, in spite of its striking successes in physics, is beset by a serious conceptual difficulty, which should perhaps be resolved before the theory is incorporated into a philosophical system. This conceptual difficulty concerns the 'reduction of a superposition', which occurs if an observable A, having sharp and distinct values in the states represented by u_i, is measured when the state is represented by $\Sigma c_i u_i$. As a result of the measurement there is a non-deterministic transition from the initial state to a final state represented by a definite one of the u_i. Although many textbooks and popular accounts say that the transition occurs when a microscopic system interacts with the macroscopic measuring apparatus, this explanation is inadequate, since the Schrödinger equation, which is the equation governing the evolution of the state, implies that the final state of the apparatus plus microscopic system will also be a superposition with respect to the observable A. Some theoreticians have concluded that the reduction of the superposition does not take place until the result of the measurement is registered in the consciousness of an observer. This desperate conclusion is unsatisfactory for several reasons.[1] It suffices to say here that if observation is a natural process, it is difficult to understand why a non-deterministic transition should occur when an observation is made, while all other natural processes are deterministic. One possible solution to the problem of the reduction of superpositions is to suppose that the evolution of the quantum state is to some extent stochastic and hence only approximately governed by the Schrödinger equation. The non-deterministic reduction of a superposition could then occur in a system remote from anything ordinarily called 'an observer'. In this way the superposition principle could be maintained in microphysics, but at the price of changing the dynamics of quantum theory. The success of a solution along this line would remove the third reservation about a quantum-theoretical modification of Whitehead's philosophy, for the modification depends primarily upon extending the application of the superposition principle. The proposal of a chance element in the evolution of the state does not disrupt the programme envisaged here, for in fact this proposal is closer to Whitehead's version of indeterminism than is the indeterminism of current quantum theory. One could

[1] E. Wigner, article in *The Scientist Speculates*, ed. I. J. Good (London 1962); also the paper by A. Shimony cited on the previous page.

even speculate that Whitehead's account of the concrescence of an actual occasion provides some insight into the way in which the reduction of the superposition occurs. Such speculations, however, are rather empty until stochastic generalizations of the Schrödinger equation are proposed and their physical consequences are studied.

A methodological remark is appropriate in conclusion. It has been tacitly assumed throughout this paper that the hypothetico-deductive method is an appropriate instrument in philosophical inquiry. This assumption is in the spirit of Whitehead's philosophy, for he deliberately formulated a categoreal scheme which could be confirmed or disconfirmed only by examining its remote consequences (*PR* 7–8). Regrettably, the difficulties of employing the hypothetico-deductive method in philosophy are illustrated only too clearly in this paper. The conclusions which can be drawn from philosophical first principles are generally qualitative, and therefore their confrontation with experience lacks sharpness. When they are confirmed, it is gross rather than fine confirmation, and when they are disconfirmed there is often a plausible way of saving the appearances. The moral, however, is not that the hypothetico-deductive method should be abandoned. Rather, it is to seek refinements of philosophical first principles and liaisons of these principles with scientific hypotheses, in such a way that sharp predictions and fine confirmations may result.[1]

[1] I am deeply indebted to Dr Howard Stein for his criticism of an early draft of this paper and, more important, for stimulating and suggestive conversations over many years concerning the topics which it treats. I am grateful for a careful reading of the manuscript by Prof. J. M. Burgers.

Added in proof: An experiment by J. W. Christenson *et al.*, described in *Physical Review Letters*, vol. 13 (1964), p. 138 (and reported in *The New York Times*, Aug. 5, 1964), indicates a violation of 'time-reversal invariance' (see p. 253 above).