From atomism to Holism in 21st century physics

Mendel Sachs

Department of Physics, State University of New York at Buffalo

This article is dedicated to my very good friend and colleague, Georges Lochak. I wish him health and continued success in the coming years in his search for the truth in theoretical physics.

1. Introduction

For the sake of progress in our subject, the time has come for physics to welcome a paradigm change that has been waiting in the wings for recognition for over seven decades. It is the change in our comprehension of matter from a model in terms of discrete atomism and separability to one of continuity and holism.

The discoveries that promoted this paradigm change in the 1920s were 1) the theoretical prediction by Louis de Broglie, in 1924 in France, of the "matter wave"[1] and 2) the conclusive empirical facts of the wave nature of matter, as observed in electron diffraction studies of Davisson and Germer, in the US, and by G.P. Thomson, in the UK [2]

The debate on the atomicity of matter versus its continuous nature has been ongoing since the earliest times in our history, in ancient Greece and Asia. But the scientific discoveries about elementary matter in our own time have led this debate to a new height. The reason is that the empirical evidence seems to imply a dichotomy, called 'wave-particle dualism'. It is the following : Under some physical conditions of experimentation, the elements of matter, such as electrons, show the characteristics of discrete, localized, separable particles, while under other physical conditions of experimentation the electrons reveal the characteristics of nonlocalized, continuous waves.

The discovery that electrons have a wave nature led to a genuine quandary because the preceding view in physics was that whatever other conclusions we may draw about electrons, they are discrete, localized entities, as are all of the elementary particles of matter. It is an attitude of *naive realism.* It is the view that because the things we do sense directly seem to be localized and discrete, so must the elementary particles - things we do not sense directly - be localized and discrete.

On the other hand, the empirically confirmed continuous wave nature of material particles reveals them to be nonlocalized entities – the distribution of this matter does not actually cut off anywhere in space, except at the boundaries of the domain where it is supposed to be contained. If this domain should be all of space, then the domain of an electron would be unbounded ! Thus with this continuous view of the elements of matter, they have a nonlocalized description. The implication here, extending from the 'electron' to all of the other elementary particles, is that there are no truly separable entities ; all of the supposed 'particles' of matter are in fact correlated, though distinguishable modes of a single continuum. This is a view of holism.

Further, the particles of matter in the conventional view combine arithmetically – 3 particles plus 2 particles can only be 5 particles. On the other hand, the waves (fields) combine with interference - a combination of waves does not yield an arithmetic sum since their union entails constructive and destructive interference, depending on the relative phases of the waves. Because of the foregoing differences, the wave and particle representations for matter are not mutually compatible.

2. Wave-particle dualism

How did the physicists get out of this dilemma ? They did it (primarily the *Copenhagen school*, led by Bohr and Heisenberg) by declaring an epistemological view of *positivism.* That is to say, the *subjective attitude* was taken in which the particle-like or the wave-like characteristics of an elementary particle is said to depend on the way in which this matter is studied by a macro-observer. *This was declared to be the limit of what may be said about an element of matter.* This is the essence of the notion of wave-particle dualism in Quantum Mechanics. The notion was propounded in the 1920s as an underlying principle of the physical, material world.

In spite of the voluminous writing on this subject since the 1920s, there has been very little alteration of its theme to this time in our history, now at the dawn of a new millennium. The reason given by the majority for this positivistic, dualistic view is that it is in agreement with the experimental facts. Of course, empirical verification is a *necessary* requirement of any scientific theory. But it is not *sufficient*. For a true scientific theory must also be both logically and mathematically consistent.

In spite of the empirical agreement, the notion of 'wave- particle dualism', as well as the *positivistic* attitude that has supported it, has been disturbing to many physicists and philosophers since it was pronounced as a truth of science. This is primarily because the particle view and the continuous field view are together logically dichotomous. *Positivism* in science is a view that would be truly unacceptable if the epistemological attitude would be one of *realism*. The latter is the idea that the electron, for example, is an entity in itself, independent of our observations of it. The positivistic epistemology, on the other hand, attests that there is an irreducible subjective element in the *definition* of the electron. Its very nature that we may refer to scientifically depends on the particular way in which a macro-observer measures its properties, *at the time of these measurements*. While this view may seem strange to our 'classical' mode of thinking, it has been argued in 20th century physics that it is empirically valid and logically sound, and therefore that it is scientifically true.

3. Is the discrete model of particles necessary ?

Playing the role of '*devils disciple*', one may nevertheless ask : Was the pronouncement of 'wave-particle dualism' to underlie the basic nature of an element matter asserted because of the *assumption* made that whatever wave nature of, say, the electron that may appear in certain experimentation, it is still basically a discrete, localized particle ? Could this assumption be rooted in an unprovable prejudice at the outset ?

The claim is made that under certain types of physical experimentation, the electron reveals itself to be a wave while under other sorts of experimentation it reveals itself to be a discrete particle. The wave feature is certainly true, as shown by the electron diffraction studies. But is the discrete particle feature really true ? That is, are there experiments that *conclusively* reveal the electron to have a discrete, separable particle-like nature ? Or does this conclusion follow from extrapolations of data that may have other possible interpretations ?

Consider, for example, the cathode ray tube experiment of J.J. Thomson, wherein he discovered the electron[3]. One sees a small spot on the fluorescent screen of a cathode ray tube, interpreted as discrete electrons landing there. But in actual fact this is not a singular point. The image on the screen has a finite, though small spread. It does not actually disappear altogether until the edge of the screen is reached. Indeed, if one should examine the 'electron spot' with sufficient resolution, one would see a diffraction pattern inside of it !

It is my contention that there are *no experiments* that reveal conclusively that an electron (or any other of the 'elementary particles') is indeed a localized, discrete particle of matter. What the contemporary physicist does is to extrapolate theoretically from the observed facts to say that indeed there is a singular, discrete particle that is responsible for the non- singular, finite spread of illumination that is then identified with the electron. What is said is that this finite spread is due to the unavoidable interference between the singular electron and the measuring apparatus that views it, as explained with the *Heisenberg uncertainty principle*. But is it not also possible that there is no singular particle in the first place ? Rather, this finite spread may be a natural feature of a matter wave that is continuous, in principle, though under some experimental conditions peaked in space, as in the J. J. Thomson experiment. It is my contention that the latter view is a reasonable one. It is a view that is implied by a continuous field theory, such as the theory of general relativity as an underlying theory of matter. If this were where the truth lies, it would mean a genuine *paradigm change*. It would shift from the conceptual view of indeterminism, particularity and discreteness of matter to one of holism and continuity. In this holistic view, probability would play no fundamental role, as it does in quantum mechanics, in the explanation of the true nature of matter at any level – from the microscopic domain of elementary particle physics to the cosmological domain of the universe as a whole. The paradigm shift that I refer to is then from the concepts of the quantum theory to those of the theory of general relativity [4]. The change implies that, in some way, the mathematical expression of the theory of general relativity, as a general theory of matter in its most general form, must give back the mathematical form of Quantum Mechanics, in a limit. This is the implementation of the *principle of correspondence*, as it has applied throughout the history of science, when proceeding from one paradigm to the next. An example is Bohrs implementation of this principle in proceeding from classical physics to quantum physics.

4. Quantum mechanics from general relativity

I have argued that indeed the theory of relativity (in its special or general form) and the quantum theory – in terms of their full axiomatic and mathematical bases - are mutually incompatible [5]. From the mathematical view, the quantum theory is *necessarily* a linear theory because, conceptually, it is to express a probability calculus in representing *most fundamentally* the separate atoms of a material system. On the other hand, the theory of relativity *necessarily* has a nonlinear mathematical form since, conceptually, it is to underlie the physics of a closed system. Nonlinearity also appears when the theory is expressed in the form compatible with the theory of general relativity, because it must necessarily be expressed in a curved spacetime. This is a continuum, *holistic* view of any domain of matter – a view of a system of matter without actual separable parts, though with distinguishable modes, where probability *per se* plays no fundamental role.

Why does the theory of relativity imply the field concept and holism ? It follows from the underlying axiom of this theory : the *principle of relativity* (also called the *principle of covariance*). [6, 7] This is the notion that the laws of nature, as expressed in all possible continuously connected reference frames, must be in *one-to-one correspondence.* It is an assertion of the *objectivity* of the laws of nature.

The tacit assumption is made here, pertinent to our question, that the space and time parameters that form the language of the laws of nature are a continuous set. It then follows that the transformations of the space and time parameters from one reference frame to another (continuously connected) reference frame, that leave the laws of nature in *one-to-one correspondence*, must be a continuous set. This set is characterized by the 16 parameters, $\partial x^\mu/\partial x^\nu$ where $\mu, \nu = 0, 1, 2, 3$ refer to the time (0) and space (1, 2, 3) coordinates of our language system. The set of transformations that define covariance, according to the theory of relativity, then forms a *continuous group* [8]. The invariance of the laws of nature with respect to this transformation group is a statement of the algebraic basis of relativity theory.

It is further asserted that the underlying symmetry group of the theory of relativity is a set of not only continuous, but also *analytic* transformations. That is, the derivatives of the four coordinates $x^{\mu'}$ with respect to the four coordinates of any other (unprimed) reference frame, x^ν, must exist to all orders. The reason for this requirement is that analyticity is a *necessary and sufficient* condition in a field theory for the existence of laws of conservation of energy, momentum and angular momentum (in the local, flat spacetime limit of the generally covariant field theory). This is a consequence of *Noethers theorem.*[9]. Thus the algebra of Einsteins theory of general relativity is expressed in terms of a Lie group - a 16- parameter set of continuous, analytic transformations. I have called this "the Einstein group".

The field solutions of the laws of nature, according to the symmetry of Einsteins (general or special) theory of relativity, then behave as the basis functions of the irreducible representations of the Einstein group in general relativity, or the Poincaré group in special relativity. These must then be continuous, analytic functions of the space and time coordinates, *everywhere*. Such solutions are called "regular".

Einstein remarked often that the field solutions of the laws of nature must be regular functions. However, to my knowledge, he did not explain why this must be so. We see here that one important reason is our physical requirement of the incorporation of the laws of conservation of energy, momentum and angular momentum, with the other field laws, in the local limit.

From this holistic view, we see that there are no discrete boundaries for the field solutions for matter. Thus if $\psi_1(x), \psi_2(x), \ldots, \psi_n(x)$ are n distinguishable regular field solutions of the laws of nature, they are all mapped in a single spacetime x. All of these functions must then be correlated. The correlation follows from a single connective field $\Psi(x)$, of which they are all components.

The transformations to reference frames that are in continuously connected spacetimes $x \to x' = x + dx$, then yields the set of solutions $\psi'_1(x'), \psi'_2(x'), \ldots, \psi'_n(x')$, mapped in the continuously connected spacetime x. The principle of covariance, which is the basis of the theory of relativity, then requires that the field laws in $\psi_k(x)$ must have the same form as the field laws in a different (continuously connected) reference frame,$\psi'_k(x')$, where $k = 1, \ldots n$ denote the component fields of the closed system.

With this way of representing a material system, there are no separate 'parts'. One may instead interpret the separate component field solutions as the 'modes' of a single continuum. It is a *holistic* model of matter. It follows from the *principle of covariance* – the basis of Einsteins theory of relativity (in its general or special form).

This view is analogous to the ripples of a disturbed pond. These ripples are indeed distinguishable, but they are not separable from the pond. They are not discrete entities, with individual physical properties, such as weight, size, etc. They do not have discrete boundaries, except for the edges of the pond. If the pond were infinite in extent, there would be no finite 'cut-off' for these ripples. Indeed, all of the ripples are not more than modes of the entire pond. They are *of* the pond ; they are not things *in* it.

It is interesting that the irreducible representations of the Einstein group (of general relativity) or of the Poincaré group (of special relativity) obey the algebra of quaternions. In the book by Pontrjagin,[10] it is shown that the most general sort of associative algebra, under conditions met by the mathematical requirements of physical theories of matter, is the quaternion algebra. The set of quaternions, in turn, contains the subset of complex numbers, which in turn contains the subset of real numbers.

Thus, the *noncommutative* set of quaternions, whose irreducible, lowest dimensional form is in terms of 2- dimensional matrices, entails components that are complex functions. The basis functions of the quaternion representations are the two-component spinor variables. The most general sort of functions that solves the laws of nature in general relativity are then the *regular* spinor and quaternion field variables, mapped in a curved spacetime.

In some way, then, the spinor field variables relate to matter and to the structure of quantum mechanics. What I have found in my research program is that the mathematical structure of quantum mechanics (the Hilbert function space) emerges as a linear approximation for a generally covariant field theory of the inertia of matter. This is expressed in terms of the spinor and quaternion variables that are continuous and differentiable (to all orders) everywhere [11]. That is, these are the regular variables of the theory of matter in general relativity. It is a theory based on continuity and holism in the laws of nature.

It is interesting in this context to note that it is the group structure of the theory of relativity, in terms of its *irreducible representations*, that leads to the spinor basis functions of the laws of matter, that in turn entail complex variables. The latter, in turn, encompasses a description of the wave nature of matter. This is a feature that then follows directly from the theory of relativity, as one of its consequences. It answers the question that was initially posed by Schrödinger to Einstein : How can the theory of general relativity, if represented by the (real) variables of a tensor calculus, yield the (complex) wave nature of elementary matter, as required by Quantum Mechanics ?

The answer to Schrödinger is then that the continuous wave nature of matter is indeed rooted in the basis functions of the *irreducible representations* of the Einstein group. This is the algebraic basis of the theory of general relativity. The importance of the group structure that underlies the theory of relativity, in its most general expression, was indicated in the following 1945 comment by Einstein : "Every attempt to establish a unified theory must start, in my opinion, from the group of transformations which is no less general than that of the continuous transformations of the four coordinates. For we could hardly be successful in looking for the subsequent enlargement of the group for the theory based on the narrower group"[12]. Thus, Einstein concluded that to successfully achieve a unified field theory, one must not only examine the geometrical logic embedded in the theory of general relativity, but also its algebraic logic. It is the latter that leads directly to an expression of the theory of general relativity in terms of quaternion and spinor field variables.[13]

References

[1] L. de Broglie, Recherches d'un demi-siècle (Albin Michel, 1976), pp 99-150 ; "Divers problemes concernant les ondes et les corpuscules", Annales de la Fondation Louis de Broglie **22**, 105 (1997).

[2] C. J. Davisson and L. H. Germer, "Diffraction of Electrons by a Crystal of Nickel", Physical Review **30**, 705 (1927) ; G. P. Thomson, "Experiments on the Diffraction of Cathode Rays", Proceedings of the Royal Society (London) **A 117**, 600 (1928).

[3] J. J. Thomson, "Thomsons Experiment", in Great Experiments in Physics, ed. M. H. Shamos (Dover, 1987), pp 219 –231.

[4] M. Sachs, "Will the 21st Century See a Paradigm Shift in Physics from the Quantum Theory to General Relativity ?, Revue Internationale de Philosophie, **54**, 351 (2000).

[5] M. Sachs, Einstein versus Bohr (Open Court, 1988), Chapter 10.

[6] M. Sachs, Relativity in Our Time (Taylor and Francis, 1993).

[7] M. Sachs, Dialogues on Modern Physics (World Scientific, 1998). I am especially indebted to Georges Lochak for his very excellent Foreword to this book.

[8] L. P. Eisenhart, Continuous Groups of Transformations (Dover, 1961).

[9] E. Noether, "Invariante Variations Probleme", Goett. Nachr. 1918, p. 235. The theorem is explicated in C. Lanczos, The Variational Principles of Mechanics (Toronto, 1966), 3rd edition, Appendix II. Also see : R. Courant and D. Hilbert, Methods of Mathematical Physics (Interscience, 1953), Vol. I, p. 262. For an application of Noethers theorem to fields

see : N. N. Bogoliubov and D. V. Shirkov, Introduction to the Theory of Quantized Fields (Interscience, 1980), 3rd edition, Sec. 1.2.

[10] L. Pontrjagin, Topological Groups (Princeton, 1939), transl. E. Lehmer, Theorem 45, p. 173.

[11] M. Sachs, Quantum Mechanics from General Relativity (Reidel, 1986). The transition from the notion of a probability calculus of quantum mechanics, referring to individual particles of matter, to the concept of interaction weighting of a holistic field theory is explicated in : M. Sachs, "Quantum Mechanics from General Relativity : Particle Probability from Interaction Weighting", Annales de la Fondation Louis de Broglie **24**, 25 (1999).

[12] A. Einstein, "Generalization of the Relativistic Theory of Gravitation", Annals of Mathematics **46**, 578 (1945).

[13] M. Sachs, General Relativity and Matter (Reidel, 1982).

(Manuscrit reçu le le 31 mars 2000)