PHYSICS IN THE 21st CENTURY

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Do we see any major paradigm changes coming in the 21st century in physics – changes of fundamental ideas that underlie the material world? My answer is: Yes. It is because the leading ideas of contemporary physics are in conflict. The fundamental bases of the two revolutions of 20th century physics - the quantum theory and the theory of relativity – are both mathematically and conceptually incompatible![1] The main paradigm that has dominated 20th century physics has been that of the quantum theory. Yet the theory of relativity has given many correct predictions since its inception at the beginning of the 20th century. It must then be incorporated into all of the laws that underlie physics.

Atomism versus Holism

The initial instigation of the quantum theory was the experimental finding, in the 1920s, of Davisson and Germer, in the US, and G. P. Thomson in the UK, that the smallest particle of matter – the electron – has a wave nature, rather than the nature of a discrete 'thing'. These were the seminal experiments on the diffraction of scattered electrons from a crystal lattice. Instead of revealing the geometrical shadow of the crystal, as discrete particles would do, the scattered electrons revealed an interference pattern, as waves would yield. Preceding this experimental finding, de Broglie had postulated the existence of 'matter waves'. Then, Schrödinger discovered the equation whose solutions were the matter waves discovered in the electron diffraction experiments.

Schrödinger initially tried to make his 'wave mechanics' compatible with the symmetry requirements of the theory of special relativity. He was not able to do this, with the requirement that the matter waves were to represent the (indestructible) electrons. Subsequently, it was Dirac who showed how to represent Schrödinger's 'wave mechanics' is a relativistic way.[2] But even this improvement was not entirely satisfactory because of the way that the particle wave was coupled to electromagnetic radiation.

To overcome this difficulty and complete the theory there had to be an extension of the Dirac theory to a different formalism, called "quantum electrodynamics". This generalization did lead to added predictions that were in agreement with the empirical facts, such as the 'Lamb shift' in the energy levels of hydrogen. However, this was theoretically unsatisfactory. First, there was no closed mathematical description of quantum electrodynamics. Second, the alleged solutions were constructed and displayed in terms of infinite series that diverge. Thus there is the prediction here that all physical properties of elementary matter are infinite! Formal methods of renormalization to subtract off the infinities were discovered. However, as successful as this had been to match empirical facts, the scheme is not mathematically consistent.[3]

The Quantum Theory versus the Theory of Relativity

It is my judgment that the trouble with reconciling the quantum and relativity theories is indeed that these two approaches are mathematically and conceptually incompatible. A resolution of the problem might then be a paradigm change, replacing that of the quantum theory with the paradigm of the theory of relativity – *fully exploited.* This paradigm change entails our model of matter, dating back to the conflict in ancient Greece on the atomicity or the holistic, continuum basis of elementary matter.

One of the important atomists in an ancient Greece was Democritus.[4] His view was that any observable matter must be composed of many indestructible 'things' that characterize this matter. These are bodies that are free until they are brought into interaction with each other. On the other hand, those who believed in the continuum view of matter, such as Parmenides in ancient Greece,[4] saw the universe as a single, continuous, immovable entity. While his view of the universe was a static whole, another interpretation would say that the 'things' we experience are its multiple manifestations, not unlike the ripples of a pond. They are like the continuous, correlated modes of the entire undivided pond. The latter *holistic* view of the single continuum, being derivative of Parmenides' world, would be more akin to that of Spinoza. The former view is that of *atomism*. The latter is a view of *holism,* wherein there are no truly separate parts. It is this change from the atomistic to the holistic view of the material universe that I see as the basic paradigm change that will be recognized in physics in the 21st century.

The atomistic paradigm has dominated the thinking in physics since the ancient periods to the present time. The quantum theory views matter atomistically, even though one needs fields (of probability) - the 'matter fields' - to represent the laws of the elementary particles of matter (electrons, protons, quarks, ..) This view is non-deterministic (the laws of the elements of matter are not predetermined, aside from the (laboratory-sized) measurements on their qualities). It rejects some of the causality in the laws of nature. The view is also subjective and linear (because probabilities necessarily obey a linear calculus).[5]

On the other hand, the theory of relativity, as a fundamental basis for our understanding of matter, is holistic, based on the continuous field concept. This view, opposing the atomistic approach, was originally introduced by Michael Faraday in the 19th century, to understand the laws of electricity and magnetism. Thereby there was introduced into physics the basic conflict between the model of matter in terms of mass points and their motions, as discussed by Newton in the 17th century, and the continuous field concept to underlie all of the laws of matter. The theory of relativity (in its special or general forms) leads to the continuous field view and holism. It will be explained in more detail in later paragraphs of this essay.[6]

When, in 1927, the empirical result was revealed that the fundamental particles of matter have a continuous field (wave) form, as shown conclusively in the electron diffraction experiments, the Copenhagen School (led by Niels Bohr) refused to give up the discrete particle view. To resolve this problem, they resorted to the concept of 'wave particle dualism'. That is to say, if an experiment is designed to see the particle as a continuous wave, it is so at that time. But if a different sort of experiment is designed to see the particle as a discrete mass point, it is so at that time. This is in accordance with the epistemological approach of *positivism*. On he other hand, the opposite view of Einstein is that of *realism* - that the qualities of the electron, as a fundamental matter component, are independent of any sort of observation that may (or may not) be made by a macro-observer.[7]

It was Max Born who saw that the Schrödinger wave mechanics may be put into the form of a probability calculus. Thus, the Copenhagen School interpreted the 'matter wave' $\psi(x, t)$ of Schrödinger's equation as related to the probability density $\psi^*\psi$ for finding, *upon measurement by a macro-observer*, that the electron is at the location x at the time t. This paradigm, that the laws of nature are the laws of probability (i.e. laws of chance) then carried forth to the 21^{st} century.

The alternative view of the electron diffraction experiment is that the particles of matter are indeed fundamentally continuous matter waves. (This was Schrödinger's and de Broglie's original interpretation!) It is a paradigm change that fits in well with Einstein's view that the theory of relativity - based on the continuous field concept - underlies all of the laws of nature. It is based on a totally ordered universe and holism, where probability and measurement play no fundamental role.

The Theory of General Relativity and Holism

When one fully exploits the theory of general relativity, as a fundamental theory of matter, one is led naturally to a continuum, holistic view of matter. To demonstrate this, we start with the basic axiom that underlies this theory - "the principle of relativity". Its assertion is this: The expressions of any law of nature, as determined by any single observer, in all possible reference frames from his or her view, must be in *one-to-one correspondence*.[8]

For example, if an experimenter studies the law of a burning candle, in his or her own frame of reference, and then compares this expression of the law in any other frame of reference relative to his or her own, such as law of the burning candle in a moving rocket ship, the expressions of the law of the burning candle, in the relatively moving reference frames, must be the same. *This is equivalent to saying that the laws of nature must be fully objective.*

There may be objections to calling this principle a law of physics, asking: how could a law be a law, by definition, if it were not fully objective? That is, it seems that the principle of relativity is a tautology! – *a necessary truth*. It would be like asserting that 'woman is female'. Of course this is a true statement, but it is empty - because it is only a definition of a word! But the principle of relativity is not a tautology, because it depends on two tacit assumptions that are not necessarily true in the real world. (They are only *contingently* true). These are: 1) there are laws of nature in the first place. That is, it is assumed by the scientist that for every effect in the real world, there is an underlying cause - a law of total causation. It is then the obligation of the scientist to search for the cause-effect relations – the laws of nature to *explain* the natural effects observed. The search for such explanation is the raison d'etre of the scientist. But this law of total causation is not a necessary truth of the world. It is a law that is based on the scientist's faith in its truth.

The second tacit assumption that underlies the principle of relativity is that we can comprehend and express the laws of nature. This is where the space and time parameters come into the picture. They form a language (not the only possible language) that is invented for the purpose of facilitating an expression of the laws of nature.

The Continuous Field Concept

If we assume that the spacetime language for the laws of nature is a continuous set, then the principle of relativity requires that these laws must be preserved in form (covariant) under the *continuous transformations* from one reference frame to any other continuously connected frame. (*In principle, the spacetime language could be discrete rather than continuous. Then the laws of nature would be in terms of difference equations (governed by the rules of arithmetic) rather than differential equations (governed by the rules of calculus). Nevertheless, in accordance with all of our discoveries in science thus far, the spacetime language is continuous*). Thus the solutions of the laws of nature must be continuous functions of the spacetime coordinates. These functions are the continuous fields that underlie the true nature of matter. For example, in the case of electromagnetism, these are the solutions of the Maxwell field equations (or their factorized spinor version, to be discussed later on). A further feature, based on the requirement of the inclusion of conservation laws is that these fields must be analytic – continuously differentiable to all orders. *(This is based on Noether's theorem.*[9]) That is, it follows from the principle of relativity and the assumption that the space and time parameters is a continuous set, that the laws of nature, including the laws of conservation of energy, momentum and angular momentum, are field equations whose solutions are *regular* – continuous and analytic, *everywhere. (This is a requirement that Einstein emphasized throughout his study of the theory of (special and general) relativity).*

The Language of General Relativity

According to relativity theory, the spacetime language is used to facilitate an expression of the laws of matter. Since matter fields are generally continuously variable, it follows that the metric of spacetime must entail continuously variable coefficients. That is to say, the differential invariant metric is

$$ds^2 = \Sigma_{\mu\nu}\, g^{\mu\nu}(x)\, dx_\mu\, dx_\nu \ = \ ds'^2$$

where the sum over μ and ν is taken over the four space and time coordinates. This is a Riemannian geometrical system.

The principle of relativity then requires that the laws of nature must be covariant (form preserving) under the same set of continuous transformations that leave ds invariant, i.e. $ds \rightarrow ds' = ds$.
The metric tensor $g^{\mu\nu}(x)$ is a continuous, regular function of the four spacetime coordinates x. Because it is a symmetric tensor, $g^{\mu\nu} = g^{\nu\mu}$, it has ten independent components that reflect the material content of the closed system, that in principle is the universe. The *Einstein field equations* are then a set of ten nonlinear differential equations that determine the metric tensor components, given the material content of the system, as represented by the energy-momentum tensor of the matter, as its source.[10] It was this formalism that *explained* the phenomenon of gravity, superseding Newton's theory of universal gravitation, which *described* rather than explained gravitation in the experimentation before the 20th century. In addition, Einstein's field theory predicted all of the phenomena covered by Newton's (atomistic) theory, in addition to extra effects that were not predicted by Newton's theory.

The asymptotic limit of the Riemannian geometrical system, as the matter content is depleted towards zero (a vacuum, *everywhere*) is the Euclidean geometrical system, with $g^{00} \rightarrow 1$, $g^{kk} \rightarrow -1$, ($k = 1, 2, 3$) and $g^{\mu \neq \nu} \rightarrow 0$. Thus in special relativity the metric is: $ds^2 = (dx^{0})^2 - (dx^1)^2 - (dx^2)^2 - (dx^3)^2$. The geodesics of the Riemannian spacetime are variable curves. The family of these curves is a *curved spacetime*. The family of geodesics of the Euclidean geometry is a set of straight lines. This is a *flat spacetime*. Thus, the flat Euclidean spacetime is the ideal limit of a matterless system - a vacuum *everywhere*. Thus, the theory of special relativity, based on the Euclidean spacetime, is only true, in principle, for the idealistic limit of a vacuous universe, *everywhere*. However, special relativity may be used as a good approximation for the theory of general relativity where the actual geodesics are curves but approximated by straight line paths in particular regions. The significance of the geodesic is that it is the natural path of the unobstructed body. That is, the path of a body on a curve due to the action of an external potential in a Euclidean space, is equivalent to its natural motion in a curved Riemannian space. *This statement is the essence of the principle of equivalence.*[11]

A Unified Field Theory

According to the theory of general relativity, one does not have different domains where one type of force or another, such as electromagnetism or gravity, is in effect, while the other is not. There are no sharp boundaries in the field theory of this approach. The implication is that the continuous field solutions of these physical laws incorporate all of the possible forces that matter exerts on matter, as well as the inertial properties of this matter. It is rather that one type of force or another will dominate the others under particular physical conditions. But all forces that matter exerts on matter are present at all times – the long range electromagnetic and gravitational forces as well as the short range forces called 'weak' and 'nuclear'. The next question is: What does the general form of such a unified field take that is logically required of the theory of general relativity?

In one of his papers on the unified field theory, in 1945,[12] Einstein advised that one should not only pay attention to the geometrical logic of the laws of physics, but one should also pay attention to its algebraic logic. The latter refers to the underlying algebraic symmetry group, and its representations. What I have found is that the underlying group of the theory of relativity is a Lie group – a set of continuous, analytic transformations that project the field equations of physics, in any reference frame, to any *continuously connected* reference frame. That is, this is a *continuous group*, without any reflections in space or time. I have called this "the Einstein group". What I have found is that the *irreducible representations* of this group obey the algebra of quaternions.[13] These representations, in turn, have as their basis functions the (two-component) spinor variables. The asymptotic limit of the representations of the Einstein group of general relativity is the set of representations of the "Poincare group" of special relativity.

Thus, the algebraic symmetry group of relativity theory tells us that the most primitive fields that solve the laws of nature are the spinor and quaternion variables, mapped in a curved spacetime for general relativity or the flat spacetime for special relativity. Indeed, the reason for Dirac's relativistic generalization of Schrödinger's wave mechanics to a spinor formalism in special relativity is that the imposed symmetry was that of relativity theory, not that spin is a uniquely quantum mechanical property. That is to say*, any theory* in physics that is to conform with the symmetry requirements of (special or general) relativity theory – from elementary particle physics to cosmology – must, in its most primitive (irreducible) form, be in terms of spinor field solutions.

With the quaternion-spinor formalism in the curved spacetime, it is found that the ten relations of Einstein's field equations, that have already provided an explanation for gravity, and superseded Newton's theory of universal gravitation, *factorize* to sixteen field relations whose solutions are the quaternion variables $q^{\mu}(x)$. These are the four quaternion components of a four vector. Thus this variable has 4 x 4 = 16 independent components. The new factorized field equations then replace Einstein's 10 tensor field equations, as the fundamental representation of general relativity. The factorization occurs essentially because of the elimination of the reflection symmetry in space and time in Einstein's field equations, which was not required in the first place, since the covariance is defined in terms of a continuous group alone (the "Einstein group"). It was then shown that the 16 field equations could be separated, by iteration, into 10 equations that are in one-to-one correspondence with the form of Einstein's tensor equations, to explain gravity, and 6 equations that are in one-to-one correspondence with the form of Maxwell's equations, to explain electromagnetism. Thus, this quaternion factorization of Einstein's field equations yields a formalism that unifies gravity and electromagnetism, in terms of the single 16-component quaternion field $q^{\mu}(x)$ – this is the unified field theory sought by Einstein.[14]

A further feature of this formalism is that the geodesic equation takes a quaternion form, predicting that this is a set of four independent equations, rather than one. That is, the 'time' that parameterizes the path of a body in the curved space is defined here as a set of four parameters rather than one, as in the usual geodesic equation. (*This result is in agreement with the speculation of William Hamilton, in the 19th century, that he quaternion number system, which he discovered, would turn out to most fundamentally represent the time measure in the problems of physics).*[15]

A further implication of the quaternion expression of the field laws was that Maxwell's field equations for electromagnetism also factorizes to a pair of two-component spinor field equations. It follows here, as it did in the factorization of Einstein's tensor formalism, from the elimination in the fundamental field equations of the reflection symmetry in space and time for electromagnetic interactions. A generalization that then occurs is that, in addition to the standard scalar electromagnetic interaction, there is predicted to be a pseudoscalar electromagnetic interaction. (*A prediction of the latter was that of the Lamb shift in the hydrogen atom, calculated to be in better empirical agreement with the data than the standard quantum electrodynamics*). There is also indicated here a basis for the 'weak interaction' in the nuclear domain, as following from this generalization to spinor-quaternion form of the electromagnetic field equations.[16]

The Elementary Particle Domain

Summing up, the geometrical and algebraic logic of the theory of relativity predicts that the laws of nature must be field equations in terms of spinor and quaternion variables in a curved spacetime that unify the laws of gravity and electromagnetism. The Einstein symmetry group, when taken to its logical extreme, predicts that there are no fundamental 'spin one' particles. Thus, the 'photon' of the electromagnetic theory is not an elementary particle. Rather, it is a mode of the continuum that carries the electromagnetic interaction, at the speed of light c, from one (spinor) component of charged matter to another. This is the long range electromagnetic (scalar) interaction, as shown in the binding of the electron and proton to form the hydrogen atom. The predicted (short range) pseudoscalar electromagnetic interaction (that must accompany the scalar interaction because of the lack of reflection symmetry in the underlying field) entails the spinor form of the electromagnetic field, as a neutrino field that carries the binding of the electron and proton to form the neutron. Thus, the neutron is not an elementary particle. It is a composite of electron, proton and the spin one half electromagnetic field of coupling between them that we associate with the neutrino field.

Similarly, it has been found in this research program applied to the elementary particle domain that the pions, that mediate the short range (strong) nuclear interaction (as seen, for example, between protons and neutrons), are *composites* of fundamental particle fields. Indeed, the only elementary particle fields here are the four stable matter fields: electron, positron, proton and antiproton. The photon and the neutrino are *virtual fields* that affect the coupling between the stable fields that make up the composite elementary particle matter fields. – as modes of a continuum. The investigation shows that the numerical values of the ratio of the masses of charged to neutral pions and the ratio of their lifetimes is in conformity with the empirical data. The composite model of the kaon also yields the correct ratio of CP violation to non-violation compared with the empirical data.

Quantum Mechanics from General Relativity

One of Einstein's anticipations for the future of physics was that the formal expression of quantum mechanics would follow from a closed form field theory of matter, rooted in the theory of general relativity. That is, he believed that the asserted foundations of the quantum theory – a probability calculus, indeterminism, partial causality, and the role of measurement - are false. He believed that the quantum theory appears to have these characteristics because it is an incomplete expression of the laws of matter. This is analogous to the incompleteness of statistical mechanics to describe fully the dynamics of a many body system. Then how is it that quantum mechanics is a very accurate expression of the laws of elementary matter in the atomic and elementary particle domain, especially at non-relativistic energies?

What I have found is that Einstein was right about this. In the fully exploited theory of general relativity, the spinor-quaternion formalism leads to the full (Hilbert space) expression of quantum mechanics as a linear approximation for a nonlinear field theory of the inertia of matter, that is rooted in general relativity.[17] That is, in this view, the 'quantum phenomena' come from a general field theory as an approximation – that is to say, it is an *incomplete* description of the atomic domain. The *completed* expression is indeed a non-atomistic, holistic field theory of the inertia of matter, based on the continuous closed system in general relativity. It is generally deterministic and nonlinear. Statistics and measurement by macro-observers do not play any fundamental role, as they do in the Copenhagen view of quantum mechanics. The full derivation of this result is given in my books.[10, 16, 17]

From the Inertial Masses of Elementary Particles to Cosmology

On Mass

The quaternion-spinor factorization in general relativity leads to the formal expression of the quantum mechanical equations. This, in turn, leads to an explicit relation between the masses of elementary matter and the features of the curved spacetime.

Without going into the mathematical details here, the derivation revealing this connection of inertial mass to spacetime is as follows: One starts with the most primitive expression where the inertial mass appears in the physics of elementary matter. This is the quantum mechanical equations in special relativity, with the Majorana form of two coupled two-component spinor equations in the Euclidean spacetime. On the left side of one of these spinor equations is a quaternion operator (defined in terms of the Pauli matrices as the basis elements of the quaternion) acting on one type of spinor. On the right hand side of this equation is the second type of spinor that is a reflection of the first, multiplied by the mass parameter m. The second spinor equation is a reflection of the first.[18] *(The combination of these two (two-component) spinor equations yields the (four-component) Dirac bispinor equation that in turn restores reflection symmetry. The latter, in turn, in the nonrelativistic limit, gives back the Schrödinger wave equation.*)

To derive the mass, one first sets the right side of this equation equal to zero. One then re-expresses the left side of the equation in a curved spacetime. The constant Pauli matrices and the unit matrix, σ^μ, (the basis elements of the quaternion) then become the quaternion *field* $q^\mu(x)$, and the ordinary derivatives are replaced by the covariant derivatives. The latter introduces an extra term called 'spin affine connection', Ω_μ in the generalization: $\sigma^\mu\partial_\mu \rightarrow q^\mu(\partial_\mu + \Omega_\mu)$. The spin affine connection is a necessary term in order to make the spinor solutions *integrable.* It is the term $q^\mu\Omega_\mu$ that then leads to an explicit form for the inertial mass field (with imposed gauge invariance on the spinor formalism).

In this way the quantum mechanical formalism was derived from the Riemannian spacetime with the quaternion-spinor expression and, as a byproduct, the inertial mass field is derived from first principles in a generally relativistic theory of the inertia of elementary matter.

An important consequence of the relation between the inertial mass of elementary matter (say, an electron) and the spin-affine connection of the curved spacetime is that as the rest of the matter of a closed system (in principle the universe) tends to zero, i.e. to a vacuum, *everywhere*, the spin affine connection, and therefore the mass of the given particle, tends to zero. This is a prediction that is in accord with the *Mach principle.*

An important further prediction is that the masses of elementary (spin one-half) particles of matter occurs in doublets. These are the eigenvalues of the two dimensional mass field, that depends on $q^\mu\Omega_\mu$. A calculation yielded the ratio of masses of the electron to its heavy sister to be $2\alpha/3$, in a first approximation, where $\alpha \approx 1/137$ is the (reciprocal of the) fine structure constant. Thus the ratio m(electron)/m*(electron) is close to 1/206. This is the empirical ratio of the mass of the electron to that of the muon. The physical reasons for the appearance of the higher mass value is that the background of any given particle of matter, say an electron, is a dense sea of particle-antiparticle pairs, in their (derived) ground state of null energy and momentum. When the given electron couples to one of the pairs of this background, the pair excites and the spin-affine connection thereby changes, which in turn alters the mass of this electron. It is determined further that the excited pair in the vicinity of the given electron decays to its ground state in the order of 10^{-6} seconds, thereby restoring the heavy electron to its original minimal value. This lifetime is indeed the order of the empirically measured lifetime of the muon. Thus it has been found that the muon is explained in general relativity as a higher mass state of the electron mass doublet. The physical characteristics of the muon are identical to those of the electron, except for its inertial mass and stability.

The prediction then also follows that the proton has a heavy sister, whose mass is the order of 193 Gev. It is interesting that recent experimentation has identified the 'top quark' with a mass that is close to this. A major difference, however, is that the quark is a fractionally charged particle while the heavy proton is integrally charged.[19]

Summing up, the quaternion-spinor formalism in general relativity leads to the full (Hilbert space) formal expression of quantum mechanics as a linear approximation for a generally covariant, nonlinear field theory of the inertia of matter. An important prediction here is that the elementary particle called 'muon' is explained in general relativity as the heavy member of an electron mass doublet. A second important prediction is that the mass of an elementary particle vanishes as the other matter of a closed system that is in its environment tends to zero.
This is in agreement with the statement of the *Mach principle*.

On Cosmology

There are several new implications of the quaternion formulation of general relativity in the problems of cosmology. 1) Galaxies rotate as a natural motion, as it is seen in astronomical observations. 2) The plane of polarization of cosmic radiation must rotate as it propagates through the cosmos. This is the *Faraday Effect. This effect has been seen in astronomical observations*. 3) The dynamics of the universe as a whole is oscillating between expansion and contraction. Its configuration is spiral rather than isotropic.[20] 4) The universe is populated with a dense sea of particle-antiparticle pairs, each in a (derived) ground state of null energy, momentum and angular momentum. This medium could serve as the dark matter that is called for in the researches of astrophysics.

5) This prediction concerns the seemingly uneven distribution of matter and antimatter in the universe. The prediction in this theory gives the following scenario: At the beginning of the expansion phase of each cycle of the oscillating universe (at the 'big bangs') a fraction of the bound particle-antiparticles ionize into positively charged particles and negatively charged particles, as they rotate with the spiraling matter of the universe. These oppositely charged particles of matter thereby give rise to enormous magnetic fields of opposite polarity. Thus, the effect of the magnetic fields competes with the spiral rotation of all of the matter of the universe. The ionized matter is then separated into matter (positively or negatively charged) and antimatter (negatively or positively charged), sent in opposite directions. It then follows that while our region of the universe is populated predominantly with matter, there are regions of the universe populated predominantly with antimatter and their complex configuration complex

systems of nuclei, atoms, molecules, and larger forms made up of bound antiparticles. Thus, matter is separated from the antimatter in different regions of the universe.[21]

Holism and Realism

As it has been emphasized earlier, it is my belief that the major paradigm change in 21st century physics will be from *atomism to holism*. The epistemology will change from *positivism to realism*. Both of these changes come from the replacement of the quantum theory with the theory of relativity as the basis of the laws of physics.

The holistic view implies that there are no sharp boundaries between individual 'things'. That is, what we think of, from our subjective perceptions, as independent things, are really correlated modes of a single, continuous entity that in principle is the universe. It is opposite to the atomistic view of matter that has dominated Western thinking for thousands of years.

The view of *positivism*, proposed by the Copenhagen interpretation of the quantum theory, has led to a 20th century belief in the fundamental importance of the subjective element in our *definition* of matter and the world. In my view, it is an egocentric (pre-Copernican) innovation that will fade in the 21st century. I believe that it will be replaced by a restoration of the view of the world in terms of a totally objective entity, whether or not we humans are there to perceive all (or even a tiny fraction) of its ramifications!

References

1. These conflicts are discussed in detail in: M. Sachs, *Einstein versus Bohr* (Open Court, 1988), Chapter 10.
2. See: P. A. M. Dirac, "The Evolution of the Physicist's Picture of Nature", *Scientific American* **208**, 45 (1963).
3. The difficulty is discussed in: P. A. M. Dirac, "The Early Years of Relativity", in: G. Holton and Y. Elkana, *editors*, *Albert Einstein: Historical and Cultural Perspectives* (Princeton, 1982).
4. T. V. Smith*, editor, From Thales to Plato* (University of Chicago, Phoenix Books, 1956). Democritus, p. 39; Parmenides, p. 15.
5. The philosophy of the quantum theory is discussed in: M. Sachs, *Concepts of Modern Physics: The Haifa Lectures* (Imperial College, 2007), Chapters V, VI.
6. See A. Einstein, *Ideas and Opinions* (The Modern Library, 1994), "The Fundamentals of Theoretical Physics", p. 337; "Relativity and the Problem of Space", p. 398.
7. Wave-particle dualism is discussed in ref. 1 and in: M. Sachs, "On Wave Particle Dualism", *Annales de la Fondation Louis de Broglie* **1**, 129 (1976).
8. M. Sachs, *Relativity in Our Time* (Taylor and Francis, 1993), Chapter 2.
9. See, for example, N. N. Bogoliubov and D. V. Shirkov, *Introduction to the Theory of Quantized Fields* (Interscience, 1980), 3rd edition, Sec. 1.2.
10. The relation between geometry and matter is expressed in the Einstein field equations. It is derived in: M. Sachs, *General Relativity and Matter* (Reidel, 1982), Chapter 6.
11. M. Sachs, "On the Logical Status of Equivalence Principles in General Relativity Theory", *British Journal for the Philosophy of Science* **27**, 225 (1976).

12. A. Einstein, "Generalization of the Relativistic Theory of Gravitation", *Annals of Mathematics* **46**, 578 (1945). A sequel to this paper is by A. Einstein and E. Straus, *Annals of Mathematics* **47**, 731 (1947).
13. ref. 10, Chapters 3, 6.
14. The unified field theory is demonstrated explicitly in ref. 10 and in: M. Sachs, *Quantum Mechanics and Gravity* (Springer, 2004), Chapter 3.
15. ref. 10, p. 63
16. M. Sachs, *Quantum Mechanics and Gravity* (Springer, 2004), sec. 5.5.
17. M. Sachs, *Quantum Mechanics from General Relativity* (Reidel, 1982), Chapter 9.
18. ref. 10, Chapter 4.
19. M. Sachs, "A Proton Mass Doublet from General Relativity", *Nuovo Cimento* **59A**, 113 (1980); M. Sachs, "Interpretation of the Top-Quark Mass in Terms of a Proton Mass Doublet in General Relativity", *Nuovo Cimento* **108A**, 1445 (1995).
20. ref. 16, sec. 8.7.3.
21. ref. 16, sec. 8.9.