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On the failure of Relativistic Quantum Mechanics, Quantum Electrodynamics and Quantum Field Theory. Der Untergang der Physik

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Motivation. I attempt here to give a justification and an explanation of my scientific activity in Theoretical Physics. Nobody asked me such a question, but I feel that many would have expected me to work in the field of Elementary Particles, or Quantum Field Theories, viewed as the most elating disciplines of the modern Theoretical Physics, by their problems, abstraction degree, mathematical apparatus and many unanswered questions. Instead, I have chosen to work in solid state physics, condensed matter, classical, general and applied physics, atomic, molecular and nuclear physics, where the highest point was deemed to be non-relativistic Quantum Mechanics at most. This is schmutzige Physik, as Pauli put it, in comparison with the noble, highly elevating, spiritual, Quantum Relativity and curved spaces. As a matter of fact, Pauli was not believing that things like semiconductors may exist at all. My failure of meeting such expectations needs a clarification, which I offer here in the way of a confession.

In fact, in my youth years I have been trained as a theoretician in Quantum Field Theory, but I have soon discovered that there was no firm ground to put my feet in this subject, in spite of the hype noise made about it. I think that such an assertion needs an explanation. Perhaps it will contribute to destroy another myth in Physics. Before entering this discussion I note that subjects like Quantum Field Theory, Elementary Particles, curved spaces were considered at that time, and still are, as "broad and hot". I must confess that I have always liked more decent situations. In the scientific research activity we have principles, beliefs, information, imagination and problems, misteries; and we have also our mathematics, our mathematical language. All these are incongruent with one another, which makes difficult the life of a researcher. An absolute principle of Physics is the great Relativity Principle, which ensures that our mathematical results do not depend on the reference frame, *i.e.* our equations are covariant; this makes Physics universal, *i.e.* useful, *i.e.* a science. I have had the occasion to see this principle infringed with emphasis, in an inverse problem, where atempts were made to derive the source from waves measured far away. Fermi used to say that there are two ways of solving a problem of Physics: either we know the solution in advance, or we have an automatic mathematical apparatus which leads us to solution. Usually, we have neither. Most of us resort to beliefs, like, for instance, the belief in unification: all the phenomena, interactions, fields must derive from a single, unique interaction, field, phenomenon. Indeed, the electricity and the magnetism come together from Maxwell's theory of electromagnetism, and gravitation is the same with the motion in curved spaces, according to Einstein; the electromagnetic interaction and the weak force may have a common source, the electroweak theory, and even the strong force may be added, or rather juxtaposed. But such solutions respond rather to philosophical than to physical problems. They are solutions to solutions, and problems to problems, making things more unclear, "though, admittedly, at a much higher level". Physics seems to be more dependent on particular, real experimental situations, than on our beliefs. The unification reveals a laziness of thinking, which ends in a decay, a dissolution of imagination, like in string theory. As a physical problem, the unification is a caprice. It is much more profitable to have a critical examination of the problems Physics raises, and it does this plentifully. Only by being critical and negative can we become positive and make progress, being positive is a sure way to failure.

After all, Quantum Electrodynamics was, and still is, deemed as one of the "most precise and perfect" theory of Physics; so, if it is so perfect, why should I have worked on it? I have only had the chance to ruin it.

Classical Physics. The principle of inertia may follow from the way we perceive the space and time, but the modification brought by Newton's law introduces two big unknowns: the mass and the force. They can only be determined from experimental suggestions, from other information, all quite indirect and not entirely warranted. In Mechanics, we have to live up with this uncertainty. In Elasticity, the motion is assigned to bodies "small but large", in Fluids "small but sufficiently large to be thermodynamical"; all undefined. What makes these theories so successful, when their basis seems to be so frail? We should not think that these weaknesses are limited to the foundations of these disciplines, and they do not apear in applications. On the contrary, we encounter them at every step in particular problems. Once accepted, an unknown thing shows its fangs everywhere (Descartes). A great fundamental difficulty is brought by Electromagnetism, which endows the bodies with electrical charges and currents, which generate new things called fields, which act upon their own causes - the charges and the currents. Leaving aside that we do not know what electrical charges and currents are, we face here a serious danger of making a confusion between charges and fields. In order to have meaningful results we need to avoid the infinite self-energy, arising from the interaction of the charge with its own field, to limit the dimension of the charge from below by a finite electromagnetic radius, to have fields not too strong and to limit ourselves to relativistic corrections to the charge motion; for higher velocities, the charges disappear, in the sense that they become fields (and at low energies the fields may become particles). This is a very uncomfortable situation. The self-interaction shows itself in Quantum Electrodynamics too, where the iteration of the interaction in higher orders of the perturbation theory brings infinities. These infinities can be removed in any finite order of the perturbation theory by renormalization techniques, but not in the infinite sum of the perturbation theory, where they nullify the charges (Landau's pole). Finally, Statistical Physics and Physical Kinetics recognize that particle motion is not describable and its description would not be useful either; the statistical motion proceeds by probabilities, governed by the great Statistical Principle, which arises from nowhere. How would we connect the statistical motion with other motions? In no way, there is no connection, only compatibility; the latter, to what extent? This is a great problem.

This is the classical Physics. We can see that it displays a lot of problems, not at all trivial, minor, or less fundamental than others. The science of the classical Physics clarifies the things at the price of introducing limitations. In order to deal with these limitations a great deal of technical virtuosity is needed, as well as a profound knowledge of the principles. This is a delicate endeavour, which is possible only with a thorough knowledge and ability. Far from being schmutzig, it is an intricate science, constructed with refinement, which requires a subtle thinking. This was, and still is, a point of attraction for my scientific activity. It may not be a hot subject, nor one of a wide interest, but it is edifying.

Quantum Mechanics and the Theory of Relativity. The things changed profoundly with the apparition of the modern Physics, *i.e.* Quantum Mechanics and the Theory of Relativity. The classical Physics introduces limitations and disparities, but all these have a positive content. Quantum Mechanics and Relativity showed that things do not exist, which is a very negative knowledge. We can work with unknown things, because we know that they are unknown. But we cannot work with the non-existence, this would be a logical contradiction, a non-sense; we may not even be aware that things do not exist, and may treat the problem as if they would exist, which is a sure way to failure. "In Physics we talk, or should talk, only about what exists". However, these two disciplines, while showing that things do not exist, still put forward equations about their non-existence, which, however, is a positive knowledge. The danger is that limiting ourselves to equations only, we lose the guiding principle of our psychological sanity and are at the great risk of introducing contradictions. The latter have not been slow, and occurred in Relativistic Quantum Theory and the Quantum Field Theory.

There are several ways of introducing the basic philosophy of the Quantum Mechanics, from several departure points and by following several paths. Perhaps the most direct one is the recognition made by Planck that mechanical motion proceeds by quanta of action h. This already means that we have certain limitations in defining (measuring) simultaneously the position and the momentum, as well as the time (duration) and the energy (which is Heisenberg's uncertainty principle). Moreover, if we cannot go below (or beyond) Planck's constant h, it follows that the motion is global, not local. A global motion requires boundary conditions, and has normal, discrete eigenmodes, which is very pleasant, because they lead to discrete energy levels, in agreement with experience. Moreover, a global motion also requires a wave ψ, which implies a frequency equal to energy divided by h and a wavelength which is h divided by momentum, which are Einstein's and de Broglie's quantization laws, respectively; and the normal modes of the energy are given by the hamiltonian, quantized with operators of the form $i\hbar\frac{\partial}{\partial t}$ for energy and $-i\hbar\frac{\partial}{\partial \mathbf{r}}$ for momentum, which is Schrodinger's equation. In addition, mean values of the operators look like weighted averages over normal modes, which imply that the wavefunction ψ is an amplitude of probability (Born). All these are in line with classical Physics, Quantum Mechanics exhibiting limitations in the same way as the classical Physics does. However, it has a very unpleasant dormant surprise. The wavefunction, which is the basic object of the Quantum Mechanics (equivalent with the off-diagonal matrix elements), oscillates and vibrates; consequently, it is the same only after an integral number of periods, or over limited ranges of its slowly-varying envelope (which amounts to say that it is lost there). Therefore, as long as the wavefunction exists, what happens inside its period? Inside its period the wavefunction has indefinite values, which means that the object it describes does not exist there. The object does exist only from time to time and only from place to place, whenever and wherever, possibly, we measure it. This is both a limitation, which is useful, and is transformed into positive knowledge as long as we are interested, for instance, in estimating lifetimes and mean freepaths of particles (which means indeed a limitation), but, also, it is a lack of knowledge, it is a "nothing". If we are going to work with the nothingness, then we are left to work only with equations without object. We do not know in fact what those equations refer to ("equations become smarter than people"). In non-relativistic Quantum Mechanics this dark side of the things does not appear too troublesome, there we make use mostly of the limited knowledge brought by the wavefunction over many periods; but in Relativistic Quantum Mechanics and Quantum Field Theory it plays a central role, and leads to contradictions.

A similar situation is brought by the Theory of Relativity. Space and time are basic tools and concepts in Physics. If the equations of Physics are going to show the same things in different reference frames, *i.e.* if they are going to be invariant (covariant) under changes of space and time, then these changes must connect the space and time. Space and time are not separate anymore, they are not distinct anymore (though we have distinct symbols and places for them in our equations!). They are in fact the same thing, which means that, in fact, they do not exist anymore, there exists only a "space-time continuum". This continuum makes sense, *i.e.* it can be measured, only if its points are connected by velocities lower than or equal with the speed of light in vacuum. The points which are linked by velocities greater than the speed of light are meaningless. They both exist and do not exist. This is a logical non-existence, of the same type as the quantum-mechanical wavefunction.

The non-existence of bodies and space and time is the basic content of the two modern physical theories, Quantum Mechanics and the Theory of Relativity, which, by such tenets, are indeed revolutionary theories. They are revolutionary because, unfortunately, their content is negative. These theories, in esence, are theories about nothing. This means much more than an uncomfortable situation, this is the end of Physics, der Untergang der Physik.

Relativistic Quantum Mechanics and Quantum Field Theory. These theories attempt to answer the question: what is the quantum behaviour of the motion at high, relativistic velocities? First, we should see to what extent is this question legitimate. It is not quite legitimate. This would be a unification of the Quantum Mechanics and Relativity, would it not, therefore, be an impossibility? At high velocities we have high energy and high momenta and the action would not be comparable with h, except for very short times and lengths. We are not interested in very short times and lengths, because we know of nothing interesting at such small scales. More, precisely inside these small scales things do no exist. The "most elementary" particles have no structure, at their own time-space scale they do not move, they do not change; they are only a collection of properties which may exist or may not. In addition, we have seen above that Quantum Mechanics makes a sharp distinction between space and time, between momentum and energy, while the Theory of Relativity unites the space with the time, momentum with energy. Depending on the reference frame, momentum may become energy, and viceversa, portions of time become space, and viceversa. Would not such an observation suffice to dismiss beforehand a Relativistic Quantum Mechanics and a Quantum Fied Theory? "Who ordered them? They are not only impossible, they are also unnecessary". Basically, such a primary contradiction prevented, and still prevents, me from approaching such research subjects, at least in the terms they are formulated here. However, in view of so many people dealing with them, it would not be inappropriate to discuss them more, although dicussing things which are contradictory is not only difficult, but especially impossible. In our discussion we shall discover gradually that people say that they do something and in fact they do something else. It is very difficult to talk with people who are not able to say what they do. I hardly believe that I would have had any chance to make myself understood in talking with such people. Then, why should I have worked in their field? Not knowing what they do, they have transformed their endeavour into a dogma. "Shut up and calculate!".

Let us point out another basic difficulty concerning these theories (highlighted by Landau and Peierls). A relativistic particle has a minimum momentum mc, which means that its quantum-mechanical behaviour should proceed over distances of the order $\Delta x \simeq \hbar/mc$ (Compton wavelength), or larger. Incidentally, for radiation $\Delta x \simeq \frac{\hbar c}{\hbar\omega} = \lambda$, which shows that distances have no meaningful sense inside the wavelength (and time is meaningless inside a period). This means that we cannot define a precise location x, so we cannot have functions of x, in particular we cannot have wavefunctions. The quantum-mechanical description of a relativistic particle seems impossible. Similarly, a relativistic particle has a minimum energy mc^2, which means that we cannot have time duration less than $\Delta t \simeq \hbar/mc^2$. Again, we are not able, it is impossible to define a quantum-mechanical behaviour for relativistic particles. This is a serious objection against doing Relativistic Quantum Mechanics. More exactly, it is impossible to do relativistic quantum-mechanical motion in space and time. Then, what is doing under this name? It should be something else. What?

On the other side we have electromagnetic radiation which is quite relativistic and, according to Einstein, it is also very quantum-mechanical. In what sense is this thing so? A pertinent starting point would be to leave aside the hamiltonians (which Quantum Mechanics makes basic use of) and use directly equations of motion. The electromagnetic radiation provides a good example of this procedure. For the electromagnetic field we start with Maxwell's equations. Then, we write down the energy of the electromagnetic radiation and notice that it may be written as a collection of harmonic oscillators. We note that this energy is not a quantum-mechanical hamiltonian, it is the energy (and the momentum) derived in the sense of Lagrange, or Hilbert, from the Maxwell equations; it is a field energy. We know how to quantize the harmonic oscillators, so we do that for the harmonic oscillators exhibited by the energy of the electromagnetic radiation. But, attention! This quantization is not in space and time, it is in generalized coordinates, which are Fourier transforms of the fields. It is a quantum-mechanical motion in a completely other space. In addition, a scheme of accounting for the energy levels of these oscillators is provided by the space of the so-called occupation numbers, where the fields are not wavefunctions (so, there is no probability assigned to them), they are operators, which evolve in time according to the so-called Heisenberg representation, which is nothing but a formal recogniton that the field operators are expanded in plane waves; it is worth noting that the quantum-mechanical equations of motion of the electromagnetic radiation are not Maxwell's equations. This is not a Quantum Mechanics in space and time, it is a Quantum Mechanics in the space of the fields, the coordinates are Fourier transforms of the electromagnetic vector potential and, in addition, the occupation-number scheme provides operators in the so-called second quantization; having operators, this scheme is called a quantization scheme, though it is completely different from the original quantization of the Quantum Mechanics. This treatment of the electromagnetic radiation shows that the electromagnetic field consists of an indefinite number of photons, *i.e.* quanta of energy, and momentum, in agreement with Einstein's suggestion of energy quantization; the photons are quantized by commutators, their number is unlimited, they are bosons. The photon is not a quantum-mechanical object, it has no wavefunction; it is an eigenmode of Maxwell equations, in the context of the field and second quantizations, *i.e.* for quantized Fourier amplitudes of the electromagnetic fields and the quantized occupation numbers. This quantization of the electromagnetic field looks as being legitimate and it fits well the non-relativistic Quantum Mechanics in the radiation theory of Dirac, whence one can see that requirements of uniformity, *e.g.* both theories be relativistic, are futile. It is worth noting that in deriving the photons we discard an infinite energy, which corresponds to the vacuum. Such a procedure may be legitimated by viewing the photons as elementary excitations of a vacuum ground state. This ground state has its own dynamics, as shown very convincingly by the Casimir forces, produced by the so-called vacuum fluctuations; it is not the infinite energy of the vacuum which is responsible for these forces, but its variations, which is in line with viewing the photons as elementary excitations (*i.e.*, changes in the vacuum ground state). The scheme of quantization of the electromagnetic radiation is an application, or a formal extension, of Quantum Mechanics to fields and occupation numbers, where the motion occurs in other spaces than the space and the time where the electromagnetic radiation is relativistic. It is a field theory, which may be called a Quantum Field Theory, but it is more appropriate to call it the quantum theory of radiation, because terms like Relativistic Quantum Mechanics and Quantum Field Theory are used for relativistic particles (like relativistic electrons) or other relativistic fields. The quantum treatment of the (perfectly relativistic) electromagnetic radiation is not a relativistic quantum mechanics, it is the quantum theory of radiation. Is this extension of Quantum Mechanics legitimate? It is, since for large number of occupation the fields become classical and even coherent, a state which has been shown to exist in lasers, for instance. In particular, this scheme of quantization showed that low electromagnetic fields do not exist, there exists only the effect they produce. However, we should note that as long as the quantized electromagnetic field is not determined, due to the existence of the photon, it cannot be subject to relativistic transformations, which require determined functions. This points out a profound contradiction between Relativity and Quantum Mechanics.

The things are different for electrons. Here, we have not an equation of motion and an energy, to leave aside the energy (hamiltonian) and to start with the equation of motion. We can only start with the equation provided by the classical hamiltonian, which would correspond to the standard approach of the Quantum Mechanics. The energy is given by $E^2 = p^2c^2 + m^2c^4$ (with well-known notations) and the quantum-mechanical equation would be the well known Klein-Gordon equation

$$-\hbar^2 \frac{\partial^2 \psi}{\partial t^2} = -\hbar^2 \Delta\psi + m^2c^4\psi \quad , \tag{1}$$

which looks like a wave equation with mass. We may adopt this equation as the equation of motion for the field ψ, which is not a wavefunction, as is well known, and derive from it the field energy through energy conservation (the so-called Lagrange, or Hilbert, energy-momentum tensor). The quantization would be made upon the field ψ, following the example of the electromagnetic radiation. Unfortunately, there is a basic difficulty with equation (1). The terms which inlude $\hbar^2$ describes motion, while the term m^2c^4 is a rest energy. The only possibility to treat them on equal footing is to view the electron mass as a motion variable. This leads us to admit that the electron may be created or destroyed, as a quantum (like the photon); moreover, the electron field would be quantized by anticommutation rules (since it either exists or not exists), *i.e.* the electron would be a fermion, in contrast with the photon; in addition, since the electric charge must be conserved, we should accept the existence of an electron with a positive charge, *i.e.* the positron, which we call the electron antiparticle. We can see that equation (1) has far-reaching implications.

It is hard not to believe in such a scheme of quantization as long as the positron was discovered, it is an experimental fact. Moreover, Dirac insisted to derive from the same object, the relativistic equation $E^2 = p^2c^2 + m^2c^4$, both the equation of motion and the energy. As it is well known, this goal is achieved by splitting the quadratic energy equation into two linear equations $\gamma_\mu p^\mu \mp mc = 0$, where γ_μ are the Dirac matrices. This led to the Relativistic Quantum Mechanics, through $\gamma_\mu p^\mu \psi - mc\psi = 0$, $p^0 = i\hbar\frac{\partial}{\partial t}$, $p^\alpha = -i\hbar\frac{\partial}{\partial x_\alpha}$, $\alpha = 1, 2, 3$ ($\mu = 0, \alpha$). However, Dirac's approach is not in the spirit of the Quantum Mechanics (actually, it cannot, and should not be, the spirit must be that of a Quantum Field Theory, as we have learnt from photons' lesson), because Dirac equation leads to negative energies, which are not in the relativistic energy given by $E^2 = p^2c^2+m^2c^4$. The negative energies may be viewed as lost energies, as for photons, but for electrons they are associated with positrons. The meaning of the Quantum Mechanics is to describe the motion at a scale of small action, comparable with h, while recovering the classical motion for $h \to 0$. Dirac equation does not recover the classical motion in the limit $h \longrightarrow 0$, neither the non-relativistic Schrodinger equation in the limit $c \longrightarrow \infty$. Indeed, let us examine explicitly the classical limit $\hbar \longrightarrow 0$. In $-i\hbar\frac{\partial\psi}{\partial x}$, written as $-i\hbar\frac{\Delta\psi}{\Delta x}$, we put $\hbar = \Delta p \Delta x$ and $\psi \sim e^{i(kx)}$, where $\phi = kx$ is the spatial phase; we take Δx, $\hbar \longrightarrow 0$ and Δp small; then we have $-i\hbar\frac{\Delta\psi}{\Delta x} = \Delta p \Delta\phi \cdot \psi$, where $\Delta p \Delta \phi$ is the classical momentum p, for large phases $\Delta\phi$, and ψ may be dropped out, as being a multiplication factor. It follows that $-i\hbar\frac{\partial\psi}{\partial x}$ becomes the classical momentum p in the classical limit $\hbar \longrightarrow 0$ (and the particle becomes perfectly localized). A similar analysis leads to replacing $i\hbar\frac{\partial\psi}{\partial t}$ by the classical energy E in the limit $\hbar \longrightarrow 0$, since the phase is now $\phi = -(Et)$. In the classical limit the Schrodinger equation becomes $E = p^2/2m + V$ and the Klein-Gordon equation becomes $E^2 = p^2c^2 + m^2c^4$, which shows the consistency of the quantization procedure. Obviously, the scheme of taking the classical limit described above can be inverted, which leads to finding out the correct quantum-mechanical forms of classical energy equations. If we apply the classical limit to the Dirac equation, we get $\gamma_\mu p^\mu = mc$, which is not the classical equation $E^2 = p^2c^2 + m^2c^4$ ($p_\mu p^\mu = m^2c^2$). It is true that we get also $\gamma_\mu p^\mu = -mc$, which combined with the former equation gives the quadratic equation. But the combination is not the same as the combined factors. The negative energies predicted by the Dirac equation do not disappear in the classical limit; the classical electron has not negative energies. Similarly, in the non-relativistic limit the Dirac equation does not become the Schrodinger equation, unless we use the quadratic-energy form of equation, *i.e.* unless we use twice the Dirac equation. That means to use both $\gamma_\mu p^\mu - mc = 0$ and $\gamma_\mu p^\mu + mc = 0$, according, indeed, with the splitting of the quadratic equation, but these two equations are for different wavefunctions, not for the same. Simply, Dirac decided to use one of the equations $(\gamma_\mu p^\mu \mp mc)\psi = 0$ (they are the complex conjugate of each other). The Dirac equation is about something else, it is not about the electron motion, not about relativistic quantum mechanics. It is not a quantum field equation either, because it does not address the scheme of the quantum field theory showed by photons. The fact that the Dirac equation has not a classical limit is my basic objection against this equation.

What is the Dirac equation about? First, it is about a non-sense, because it views the ψ as a wavefunction, *i.e.* it introduces the conserved probability current $j^\mu = c\overline{\psi}\gamma^\mu\psi$, $\partial_\mu j^\mu = 0$ ($\overline{\psi} = \psi^*\gamma^0$), while the wavefunction does not exist. In particular, we can see that the probability moves with the speed of light in vacuum. A formal manipulation of mathematics does not lead necessarily to meaningful results, especially when contradictions are involved in manipulation. The introduction of the vector current $j^\mu = c\overline{\psi}\gamma^\mu\psi$ has important consequences; its vectorial character requires ψ to be a bispinor and the matrices γ^μ to be a vector and a bispinor written in matricial form. Since these objects are spinors, *i.e.* since they are invariant to Lorentz transformations, they recover, in their eigenvectors, the relativistic quadratic form $p^2 = m^2c^2$; this is why the linear Dirac equation seems to bear relevance upon the original Klein-Gordon equation. Unfortunately, this feature is self-contradictory, as we may have expected.

Indeed, by applying twice the Dirac equation with electromagnetic field $\gamma_\mu \left(p^\mu - \frac{e}{c}A^\mu\right)\psi - mc\psi = 0$ we arrive at the equation

$$(p_\mu - \frac{e}{c}A_\mu)(p^\mu - \frac{e}{c}A^\mu) - \frac{1}{2}i\frac{e\hbar}{c}\sigma^{\mu\nu}F_{\mu\nu} = m^2c^2 \quad , \tag{2}$$

where $F_{\mu\nu}$ is the electromagnetic field and $\sigma^{\mu\nu} = (\boldsymbol{\alpha}, i\boldsymbol{\Sigma})$, $\boldsymbol{\alpha} = \gamma^0\boldsymbol{\gamma}$, $\boldsymbol{\Sigma} = -\frac{1}{2}i\boldsymbol{\alpha}\times\boldsymbol{\alpha}$; this indicates that the electron has a spin (1/2). It follows that the Dirac matrices are associated with an internal motion of the electron (Zitterbewegung); indeed, if the electron has an intrinsic angular momentum, it should have an intrinsic motion. Similarly, the negative energies, present in the Dirac equation, correspond to an internal motion, the Dirac matrices correspond to internal states of the electron, formally similar with the quantum states, and the Dirac probability is an internal probability. But, if the internal probability flows (with velocity c!), it flows in space and time, together with the electron (which does not move with velocity c!), so it does not look like an internal probability, because it flows. These are serious self-contradictions of Dirac's theory, which reflect the fact mentioned above that we cannot speak meaningfully about contradictions, about things which do not exist. Also, it is worth noting that being inside the pointlike electron, the internal motion should be inside the period of a wavefunction, *i.e.* it would not exist. Or what are, what realities describe, the Dirac matrices?

An internal motion which modifies itself while the electron moves is a non-sense. Moreover, since the modification is located inside a wavefunction period, it appears only at very short times and over very short lengths, *i.e.* at very high energies. Since it involves negative energies, it follows that the internal motion produces other kinds of particles, with negative energies. The Dirac equation is about the production of new particles, and destruction of others, over very short distances and in very short times, where the probability propagates with the speed of light; practically, it is an instantaneous creation and destruction, in the sense of the instantaneous relativistic space-time process. In view of the difficulties with the Dirac equation and the quantum field theory derived from it and because its internal self-contradictions, its meaning was relegated to creation and destruction of new particles; consequently, the field theory was reduced to the S-matrix of the scattering theory, and the whole description of the motion of the electrons and positrons was reduced to the unitarity and the analiticity of the S-matrix. This philosophy, originating in the linear Dirac equation, was applied to the whole theory of elementary particles, which is not anymore a theory of motion but, instead, it is a theory of production and destruction of particles; these particles are representations of the Lorentz group and internal symmetries like those of the groups $U(1)$, $U(2)$, $U(3)$, etc. In addition, other local gauge symmetries suggested new interactions between new particles (Yang-Mills fields), which are used in estimating the S-matrix in scattering theory. The local gauge symmetries tell that the internal state of the particles depends on the space-time position, such that there is no surprise that they produce interactions. As convenient as such a theory of new interactions may appear, it is no reason to see why the internal state would depend on position. The interacting fields of the theory of the elementary particles tell nothing, while the internal symmetries are only a zoology, formulated, admittedly, in superior terms. Both serve well the very limited goals of the theory of elementary particles. The theory of elementary particles is a static theory which does not produce any conceptual motion. This is my main reason of having not worked in this field. It is impossible and meaningless to describe the quantum relativistic motion, so we decided to describe creation and production of particles according to their internal states, which is a very limited goal. In addition, this description mixes up the internal motion with motion in space and time (through $\gamma_\mu p^\mu$), which may entail, and it does, technical and conceptual impossibilities.

It is often claimed that the theory of elementary particles discovers the ultimate constituents of the nature (by creating new particles (fields), and destroying others), so it should be attractive. But it is not my duty to find out the ultimate constituents, especially if these ultimate constituents tell nothing, produce nothing. My duty is to get understanding and share it with my fellows, because the understanding produces answers, questions, surprises, a conceptual motion which is happiness. The ultimate answer is not happiness, it is the end of Physics. Physics ended, died, because it answered, as it is claimed, the ultimate question. Would it be attractive to work in a dead field?

The existence of negative energies in Dirac equations led to the filled vacuum and the hole theory. The existence of negative energies for relativistic bosons, on the grounds that energy is $\pm\sqrt{p^2c^2+m^2c^4}$, led to the rejection of the hole theory and to the adoption of antiparticle procedure. However, variations of the Fermi sea of negative energies are real in the Casimir forces.

The existence of the spin is viewed as a great success of Dirac's theory, being due to the Dirac matrices which, in turn, arise from relativity. However, the Klein-Gordon equation may be generalized to

$$\begin{aligned}\gamma_\mu\gamma_\nu p^\mu p^\nu = \left\{\tfrac{1}{2}\{\gamma_\mu,\gamma_\nu\}+\tfrac{1}{2}[\gamma_\mu,\gamma_\nu]\right\}p^\mu p^\nu = \\ = p_\mu p^\mu + \tfrac{1}{2}[\gamma_\mu,\gamma_\nu]p^\mu p^\nu = p_\mu p^\mu = m^2c^2 \quad ,\end{aligned} \tag{3}$$

which, in the presence of the electromagnetic field, becomes equation (2) ($\frac{1}{2}[\gamma_\mu,\gamma_\nu]=\sigma_{\mu\nu}$). The internal states remain, but they are not quantum-mechanical (or they are in a generalized sense), and no probability is assigned to them. Indeed, if there exist internal states which give a 1/2-spin, then we need at least one spinor, which, however, does not make the equation Lorentz invariant; we need two more states (at least), which means negative frequencies (not energies!) and Dirac matrices and the quadratic form $\gamma_\mu\gamma_\nu p^\mu p^\nu$. There exist two internal spin states and another two, corresponding to positive and negative frequencies. For a field-theory starting with the Klein-Gordon equation (generalized according to equation (2)), we need to include all these four states. The interaction of the electron with the electromagnetic field may be approached by using directly equation (2) and the energy generated by it.

Equation $\gamma_\nu \pi^\upsilon = mc$ can be multiplied by $\gamma^\mu \pi_\mu = mc$, where $\pi_\mu = p_\mu - \frac{e}{c} A_\mu$, to give

$$\begin{aligned} \gamma^\mu \gamma_\nu \pi_\mu \pi^\nu &= \left(\tfrac{1}{2}\left\{\gamma^\mu, \gamma_\nu\right\} + \tfrac{1}{2}\left[\gamma^\mu, \gamma_\nu\right]\right) \pi_\mu \pi^\nu = \\ &= \pi_\mu \pi^\mu + \tfrac{1}{4}\left[\gamma^\mu, \gamma_\nu\right]\left[\pi_\mu, \pi^\nu\right] = m^2 c^2 \ , \end{aligned} \tag{4}$$

since $\frac{1}{2}\left\{\gamma^\mu, \gamma_\nu\right\} = \delta^\mu_\nu$; in addition, $\frac{1}{2}\left[\gamma^\mu, \gamma^\nu\right] = \sigma^{\mu\nu}$ and $\frac{1}{2}\left[\pi_\mu, \pi_\nu\right] = -\frac{ie\hbar}{2c} F_{\mu\nu}$. On the other hand we may multiply equation $\gamma_\nu \pi^\upsilon = mc$ by γ^μ on the left and π_μ on the right, to get

$$\begin{aligned} \gamma^\mu \gamma_\nu \pi^\nu \pi_\mu &= \left(\tfrac{1}{2}\left\{\gamma^\mu, \gamma_\nu\right\} + \tfrac{1}{2}\left[\gamma^\mu, \gamma_\nu\right]\right) \pi^\nu \pi_\mu = \\ &= \pi_\mu \pi^\mu + \tfrac{1}{4}\left[\gamma^\mu, \gamma_\nu\right]\left[\pi^\nu, \pi_\mu\right] = m^2 c^2 \ ; \end{aligned} \tag{5}$$

we can see that the sign of the spin-field interaction changes, which is not a comfortable situation.

A quantum field theory which starts directly with the quadratic equation (2) makes a clear-cut distinction between the internal states and the external, quantum-mechanical states, while the linear Dirac equation mixes up the internal states with the external states; this mixing up is both self-contradictory and illegitimate (and limited itself in fact to production of new particles and destruction of others). We would expect that the positron states appear naturally, as elementary excitations of the ground-state, the critically large atoms and the Klein paradox would require to account for the dynamics of the ground state, as the pair creation would, or the Pauli anticommutation rules for the field operators. The basic point is that a quantum field theory should be conducted as a theory of both the ground-state and the elementary excitations. The ground-state infinitely filled with negative energies serves to view the electrons and the positrons as independent entities, which leads to Pauli anticommutation relations for electrons and positrons and the relation spin-statistics. But the dynamics of this ground state is governed by excitations which imply, basically, electron-positron pairs, for the charge conservation; therefore, they are described by boson operators. As long as we include field operators with negative energy (corresponding to positrons) and view them as obeying a quantum-mechanical internal scheme, their energy implies anticommutation rules. The existence of two energies, one given by $i\partial\frac{\partial}{\partial t}$, which leads to anticommutation relations and Pauli's exclusion principle, and another given by equation (2), which describes the motion and the interaction, makes the distinction between the ground-state and its excitations a subtle question, which deserves much more attention.

The Dirac theory of the electron has ever enjoyed an enormous success, a universal acclaim; I would say, it is too successful. Nobody addressed ever its fundamental self-contradictions. It is an all-conquering theory, which marches gloriously. It is very unlikely that an alternate electron theory would ever enjoys any consensus. Even if it would exist, it would appear as very different. This is enough and already too much for anybody to avoid looking for such a theory. This is why I never worked in Relativistic Quantum Mechanics, Quantum Field Theories, or Elementary Particles.

Interaction. It is claimed that relativistic free fields of radiation or electrons are quantized, by photons and electrons and positrons, respectively. However, there is no experiment to prove (or disprove) this quantization, because any such experiment would imply a detection, and any detection would transform the free fields into interacting fields. The quantization of the relativistic free fields remains an empty scheme. Moreover, when interacting, the fields are quantum-mechanical, and, consequently, they are not relativistic anymore; in quantum-mechanical interaction the coordinates are not determined, the field themselves behave globally, and the change of coordinates implied by the change of the reference frame is meaningless. There is no relativistic experiment to prove (or disprove) the quantum-mechanical nature of the interacting fields. We can see that

Quantum Mechanics remains completely distinct of Relativity; these two theories are not compatible, because there is no experiment to prove or disprove their compatibility. The interacting fields in the original Dirac's theory of radiation are not relativistic. In spite of this evidence, Quantum Electrodynamics and Quantum Theory of Fields describe the field interaction in terms of quantized relativistic free fields. This improper framework leads to the well-known divergencies, which, although removed by renormalizaton in any finite order of the perturbation theory, cannot be removed from the whole perturbation series; they show that the interaction either is zero (Landau's pole) or gives infinite results.