THE QUANTUM MECHANICAL FOUNDATIONS OF PHILOSOPHY

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Abstract

Many of the most familiar features of our everyday environment, and some of our basic notions about it, stem from Relativistic Quantum Field Theory (RQFT). We argue in particular that the origin of common names, verbs, adjectives such as full and empty, the concepts of identity, similarity, Plato's Universals, natural numbers, and existence versus non-existence can be traced to the space-time and gauge symmetries and quantum properties embodied in RQFT. These basic tools of human thought cannot arise in a universe strictly described by classical Physics based on Planck's constant being exactly equal to zero.

1. Introduction:

A more accurate version of the title, requiring the sacrifice of the obviously intended reference to some well-known titles [1], would have been "The Relativistic Quantum Field Theoretical Foundations of Philosophy". To put it briefly, the majority of works in which the words "Philosophy" and "Quantum Mechanics" appear simultaneously focus on the aspects of Quantum Mechanics that seem to be in conflict with common sense and everyday (i.e., non-laboratory) experience, whereas the aim here is to argue the opposite proposition that our everyday experiences and common sense are shaped by Relativistic Quantum Field Theory in a quite direct way.

Although the more familiar subject, which often goes under titles such as "The Philosophical Foundations of Quantum Mechanics", is thus unrelated to the issues we intend to address here, it is perhaps worthwhile to start with a few remarks about it in order to delineate more clearly the domain of our argument. At the risk of considerable simplification, one may say that the basic issue in works along the lines of [1] is the reconciliation of our usual idea of "existing objective reality" with the Quantum Mechanical picture of different "potential realities" that simultaneously coexist prior to the observation-induced collapse of the wave function. The intellectual climate among physicists has only relatively recently become tolerant towards suggestions that the Copenhagen Credo (in terms of which the preceding sentence has been formulated) could perhaps be modified or improved upon, and this has led to significantly more detailed understanding of how the passage from a Quantum Mechanical probability amplitude to classical, objective probability occurs through decoherence [2]. In short, some 70 years after the formulation of the Copenhagen interpretation, the examination of the philosophical concepts underlying Quantum Mechanics (QM) continues, but the "paradoxes" typically arise only in situations where a coherent sum of states or amplitudes is involved.

Returning to, and somewhat rephrasing, the first paragraph, the aim of the present note is to investigate the roughly reverse question of to what extent some of our most basic everyday notions, and the philosophical and mathematical concepts that are abstracted from them, owe their existence to QM, or more precisely, to a body of physical facts that find their most natural mathematical expression in Relativistic Quantum Field Theory (RQFT). These physical facts involve none of the controversial issues addressed in [1] and [2], or the difficulties connected with the renormalization procedure in RQFT. Instead, they are based on the most fundamental and commonly accepted aspects of RQFT. The reason we are not in the habit of relating our everyday experiences to RQFT is twofold: (a) The very familiarity of these experiences blunts our curiosity; furthermore, as is often the case, this familiarity is confused with our supposed ability to describe everyday macroscopic phenomena in terms of classical physics. (b) Most physicists (and even RQFT practitioners) only deal with RQFT in the context of specific scientific problems, reinforcing the perception of the theory as something rather esoteric and far removed from everyday phenomena.

In order to understand points (a) and (b) in more detail, it is instructive to review the way this outlook is imparted to Physics students. One starts by studying non-relativistic and then relativistic Classical Mechanics (CM), followed by classical wave motion and Classical Electrodynamics (CED). One can even learn General Relativity (GR), still without any mention of quantum physics. One is then usually given the impression that almost all macroscopic physical phenomena can be described very successfully within this classical framework, except for isolated shortcomings such as its inability to account for a few obscure experimental facts involving black-body radiation (curiously, the reason the Rayleigh-Jeans prediction truly deserves to be called a catastrophe is not sufficiently emphasized-the classical theory predicts that not only black-bodies, but all substances at non-zero temperature continually emit an infinite amount of energy!), photoelectric and Compton effects, and the discrete emission and absorption spectra of elements. In order to solve these problems supposedly limited to atomic or sub-atomic scales, where classical physics fails, QM is invoked. The removal of finer discrepancies between experiment and the predictions of non-relativistic QM require corrections based first on relativistic QM, and only then finally on RQFT. These are accompanied by increasing degrees of conceptual and computational difficulty. Given this order of exposition, one can easily come away with the idea that RQFT is a formidably complex theory with little direct relevance to our everyday experience, which is carelessly claimed to be adequately described by Classical Physics. This view is bolstered by formal demonstrations that the classical laws of Physics are recovered in the limits of quantum numbers tending to infinity and Planck's constant h going to zero. In the course of such arguments, one is sometimes inclined to forget that Planck's constant, while small on a macroscopic scale, is not exactly zero, and the macroscopic world is actually shaped by that fact.

The picture summarized in the last paragraph, while perhaps free from errors of commission, seriously suffers from a major error of omission: It completely overlooks the fact that direct manifestations of RQFT are at the root of our everyday experiences. An independent inaccuracy stems from the popular but false assertion according to which Quantum Mechanics is relevant only for physical events on a microscopic (atomic or subatomic) scale, without referring to the phase relationships in the problem. A more accurate classification of physical phenomena must take into account not only whether they occur on a macroscopic or a microscopic scale, but also whether there is coherence or decoherence. This gives rise to four combinations which we may label as (i) macroscopic-coherent, (ii) microscopic-coherent, (iii) microscopic-incoherent and (iv) macroscopic-incoherent. Lasers, Bose-Einstein-condensation, superconductivity and superfluidity are examples of the first, double-slit experiments with electron sources examples of the second, and any Quantum Mechanical problem in the microscopic domain, described successfully with random phases, is an example of the third. Finally, everyday macroscopic phenomena involving the participation of something on the order of Avogadro's number of particles with uncorrelated phases belong to the last category. It is often claimed that classical physics suffices to describe this domain. We will argue later that quite the opposite is the case: Attempting to imagine a universe truly and strictly based upon classical physics leads to a world far stranger than the one we live in. Our familiar environment and the way we think about it are shaped by macroscopic manifestations of RQFT; it is only the phases that are washed out by decoherence.

2. Some childlike questions concerning identity, similarity, integers, common names and verbs :

One possible way to start removing the lifelong accumulation of curiosity-deadening layers of familiarity with the everyday world is to ask questions similar to those sometimes raised by children, and then to address in turn the new questions raised by the first round of answers. Let us start with the following :

Q1: Why are identical twins identical?

Q2: Why do we encounter categories of objects that we can classify in groups such as spoons, cats and clouds?

Q3: What is the origin of the concept of natural numbers?

Q4: How does a glass of water get filled, and, more generally, why do objects in the condensed state occupy well-defined volumes?

These innocent-sounding questions are actually intimately linked to timeless philosophical and scientific issues. For example, the question of identity mentioned in Q1 has been examined by Leibniz [3], while Plato tried to answer Q2 in terms of "Universals". This roughly means that spoons, cats and clouds are only imperfect copies of an Ideal Spoon, an Ideal Cat and an Ideal Cloud existing in a "higher" and physically inaccessible realm, of whose existence we nevertheless have an imperfect awareness [4]. After Plato, the question of Universals continued to be a central concern in medieval scholastic philosophy and, in modified forms, is debated even today among philosophers. Whatever one thinks of Plato's explanation, it is a fact that we not only recognize such categories, but even incorporate them into our conscious or unconscious mental processes, and indeed into our language, with which we formulate philosophical problems.

Turning to Q3, one may wonder how the concept of natural numbers could have arisen without the existence of the above categories. In fact, Frege [5] tried to define, say, the natural number 3, as the property common to sets of three spoons, three cats and so on; it is difficult to imagine how such a notion could have emerged in a universe consisting of amorphous objects, each unlike any other. The fact that this definition involves set-theoretic paradoxes that had to be resolved by Russell and Whitehead [6] is an irrelevant complication for the purposes of our specific argument.

Having noted that the concept of number is linked to the existence of common (as opposed to proper) names, and traced the origin of at least some of the common names to the very strong physical similarities of the objects they represent, we can carry out a parallel analysis about verbs, with parallel conclusions. For example, we can recognize the action of eating in many life-forms and classify all such activity under the verb "to eat". Essentially, since the agents of the actions fall into categories labelled by common names, so do the actions.

Finally, Q4 is obviously related to fundamental notions of "full" and "empty", which not only are basic to our everyday thinking, but lead to questions concerning the definitions of "Matter" versus "Nothingness"; let us call this question Q5. Descartes' claim that Nature abhors a vacuum is only one example in a series of changing pictures of empty space conceived by philosophers and scientists. Physicists have gone from Newton's vacuum to Maxwell's luminiferous Aether [7] supporting electromagnetic waves, then back to a plain empty vacuum, and finally to modern versions of Aether-like media constituted of the Dirac sea, vacuum expectation values of Higgs fields, and superpositions of topologically inequivalent vacua. We can see RQFT themes already appearing in this last sentence; it will soon become clear that this is no accident.

Finally, it is certainly not far-fetched to assume that many of our geometrical ideas originate from the study of shapes of objects formed by matter in the condensed state; we will see in detail later on that many essential properties of the condensed state are direct consequences of the RQFT of electrons.

A disclaimer is perhaps in order at this point: our arguments do not preclude the possibility, or indeed the certainty, that there is a deeper physical theory which yields RQFT as an approximation at lengths much bigger than the Planck length $\sqrt{\frac{hG}{c^3}}$; in fact, the absence of a quantum-level explanation of gravitation points to the need for such a theory. However, such a theory, if and when found, must also necessarily reproduce the successful features of RQFT pertinent to the main line of thought pursued here.

3. Some answers and more questions:

Let us start with Q1, which could not have been handled prior to the understanding of DNA's role in heredity. The modern and conclusive answer is of course the identity of twins' DNAs. This of course also provides a less fantastic explanation of the obvious similarities between cats than Plato's postulation of an Ideal Cat in the World of Forms: Ignoring minor variations corresponding to different colors and sizes and so on, cat DNAs are very alike in containing instructions for one cat nose, one pair of cat eyes and one pair of cat ears per cat. To turn to question Q2 of the previous section, clearly, the "Platonic spoon" can be similarly explained: Since all human mouths and hands are similar in size and function, and since only a finite number of chemical substances are suitable for being formed into spoons, an "induced universality" operates even in the case of such man-made objects. Even a member of a category such as "rocks", consisting of relatively amorphous objects, is classifiable (a) because rocks are obtained from a limited number of elements via a limited number of geological processes, (b) our perceptions of their salient characteristics such as hardness are bound to be similar, given the similarity in human bodies and, in particular, in human sensory equipment.

These remarks immediately raise other questions such as why DNA is so stable and how it happens that the DNAs of identical twins are practically identical at the molecular level. To our knowledge, such questions were first addressed by Schrödinger in his very influential book "What is Life?" [8]. His answer is based essentially on the discreteness of molecular energy levels for quantum mechanical bound systems and the differences ΔE_{ij} between energy levels E_i and E_j of a DNA molecule typically being considerably bigger than the thermal energy kT per degree of freedom. Very schematically, we might say that if the level E_i corresponds to a cat with one nose and the higher level E_j to one with two noses, random thermal and most other environmental influences will very rarely be able to cause a transition resulting in a two-nosed cat. There are more modern and detailed explanations of the stability of DNA that are based on its being copied by enzymes from a template and other enzymes correcting errors, etc., but for our purposes these may be regarded as elaborations rather than refutations of Schrödinger's fundamental insight.

While Schrödinger's argument accounts for the stability of a single lone DNA molecule in the entire universe, accounting for the existence of other identical DNA molecules obviously requires that we now explain why all the atoms of a given chemical element are perfectly identical. This is essentially impossible in Classical Mechanics, and even Quantum Mechanics by itself provides only a partial explanation: For example, given a single proton and an electron, Quantum Mechanics predicts, via the Schrödinger equation, a definite set of discrete energy levels for a single Hydrogen atom, but does not explain why there are other electrons and protons with exactly the same properties, combining to form other Hydrogen atoms. It hardly needs to be emphasized that the existence of categories of non-living things such as spoons and rocks that we mentioned earlier also rely on all the atoms of a given element being identical with all the others; hence we must next see what lies behind the identity of the constituents of atoms.

Let us introduce the argument by focusing upon electrons in particular. It is well known that Wheeler attributed the identity of electrons to there being only one electron in the universe [9]. This is of course based on Dirac's Hole Theory, with Wheeler's additional observation that a positron travelling from the past to the future can be thought of as a negative energy electron travelling from the future to the past. The intersection points of a constant-time hyperplane with a single electron world-line going back and forth in time (with photons attached to the vertices) then represent simultaneously present electrons and positrons. Although this is a fascinating, and even useful idea (having led as a practical consequence to the Feynman propagator), it cannot even describe all the physical processes involving only electrons, positrons and photons. As an example of a process requiring a second electron unrelated to the first, consider adding to the zig-zagging electron picture a spacetime diagram of Delbrück scattering at lowest order. The diagram consists of an electron going around a square, with a photon at each corner. The inability of Wheeler's scheme to account for such processes is of course a manifestation of the fact that combining Special Relativity with Quantum Mechanics inevitably leads to a many-particle theory. RQFT is intrinsically suited to describing such many-particle systems, and we thus need not dwell any longer in Wheeler's halfway house on the way to QED, attractive though it is. Nevertheless, given our basic theme of relating fundamental philosophical concepts to RQFT, we should take note of the completely radical ontological switch implied by Hole Theory: What is normally regarded as empty space is identified with a negative energy electron sea of infinite negative charge and energy, while a hole in this sea appears to be a physical particle of positive energy and charge. Also, although we have not yet fully gone over to RQFT, we should take note of two fundamental ingredients, namely, Special Relativity and the Pauli Exclusion Principle (PEP), which already play an essential role in the above arguments. Hole theory is based on taking the negative sign in the relativistic expression $E = \pm\sqrt{p^2c^2 + m^2c^4}$ seriously. The existence of ordinary positive energy electrons then depends on all the negative energy levels already being full, and the filling process in turn is made possible by the PEP, without which the negative levels would turn into a bottomless pit (we should note in passing that this ingenious argument of Dirac implicitly assumes the existence of a minimum energy level, which, inexplicably, is never mentioned).

Finally, the PEP is an essential part of the answer to Q4 of the previous section. Filling a glass of water, surely one of our most ordinary everyday experiences, is a purely Quantum Mechanical phenomenon: The electrons of one water molecule are kept away from those of the other by the PEP. The molecules themselves are mostly "empty" in the sense that all but a few ten-thousandths of a molecule's mass is in the nucleus, which typically occupies only about one million billionth of the volume of the molecule (the volume of the Sun relative to the volume defined by the Earth's orbital radius is vastly bigger!). The reason an individual atom does not collapse down to the size of its nucleus again involves both the PEP and the Heisenberg Uncertainty Principle (HUP). Thus our very basic notions of "full" and "empty" are seen to be based entirely on two fundamental Quantum Mechanical rules, the HUP and the PEP. When we speak of filling the electronic levels in an atom, we are not just using an everyday idea as a metaphor for a phenomenon involving subatomic particles; it is the microscopic phenomenon that is responsible for our having the adjective "full" in our vocabulary. It is hard to imagine the idea of fullness ever arising in a universe consisting of bosons, which are not subject to the PEP.

A more dramatic example is provided by the numerous suicides that take place near Boğaziçi University, where I work, every year. The majority of the people jumping off the nearby bridge linking Asia and Europe die from the impact of their bodies hitting the water. Given that both the region within their bodies and the water they fail to displace sufficiently rapidly consists essentially of empty space, the deaths are directly attributable to two basic Quantum Mechanical principles, the HUP and the PEP again. We will later see that both find their most natural expressions in RQFT.

4. RQFT:

In order to explain the identity of electrons in terms of RQFT, we observe first that the main dynamical entity in a Field Theory is the field itself [10]. This is a very different viewpoint than the "particle picture", which, even after relativistic and Quantum Mechanical refinements and modifications, still uses the idea of a pointlike particle in the presence of external forces as its basic ingredient. In contrast, whether classical or quantum, relativistic or non-relativistic, a typical field is thought of as a dynamical system pervading all of space for all times. The further qualifying words "relativistic" and "quantum" have very specific meanings: By "relativistic" here we mean a theory in which the fields and states transform as well-defined representations of the Poincaré group. We thus limit the discussion to flat Minkowski space and neglect effects of space-time curvature. This description holds to an excellent approximation in our everyday physical environment.

The quantum nature of the theory can be represented in a number of different and more or less equivalent ways such as canonical or path-integral quantization. We will adopt the canonical approach based on equal-time commutators or anti-commutators, as it expresses most directly the features we intend to emphasize. Dirac [11] aptly calls these (anti)commutators "the quantum conditions" since it is through them that quantum characteristics are imparted to a theory initially formulated in classical terms. The HUP is in fact a consequence of the quantum conditions in particle Quantum Mechanics; turning this around, we might say that field quantization via the canonical method amounts to extending the HUP from particle Quantum Mechanics to Field Theory.

The building of a RQFT within the above framework makes use of a number of fundamental theorems and mathematical techniques such as Wigner's method of obtaining and classifying the representations of the Poincaré group, Pauli's Spin-Statistics theorem[12], derivation of the Bargmann-Wigner [13] equations for fields of a given spin and Noether's theorem. To the extent it is possible, we will try to rely on qualitative arguments in tracing the questions of section 2 to this formidable-sounding collection of mathematical physics results. This will also be helpful in allowing us to see direct consequences of the formalism in the everyday world without being lost in sophisticated and abstract mathematics.

Let us start with the Poincaré group. As emphasized by Klein and Weyl[14], a group is a collection of operations leaving a certain "object" unchanged. This amounts to classifying the symmetries of the object. When the “object” in question is the laws of Physics in a space-time with negligible gravitation-induced curvature, the symmetries can be classified as follows: (i) No point in four-dimensional space-time is privileged, hence one can shift or translate the origin of space-time arbitrarily in four directions. Noether’s theorem then implies there are four associated conserved quantities, namely the three components of space momentum and the energy. These four quantities naturally constitute the components of a 4-vector $P_\mu, \mu = 0, 1, 2, 3$. (ii) No direction is special in space; leading to three conserved quantities $J_i, i = 1, 2, 3$. (iii) There is no special inertial frame; the same laws of Physics hold in inertial frames moving with constant speed in any one of the three independent directions.

As we suggested above, it is possible to get a non-mathematical insight into Noether’s theorem relating symmetries to conserved quantities; in fact the argument we will present, due to John Philoponus [15], dates back to the 6th century AD! Consider a single particle moving in a completely homogeneous space. It cannot come to a stop or change its velocity because this would have to happen at some particular point, but all points being equal, it is impossible to choose one. Hence the particle has no choice but to move at constant velocity or, in other words, to conserve its linear momentum, which Philoponus called “impetus”. It is easy to extend the argument to a rotating object in an isotropic space and conclude that it cannot come to a stop at any particular angle since there is no special angle; hence its angular momentum is conserved.

It is well-known that (ii) and (iii) amount to covariance of the laws of physics under rotations in a four-dimensional space with a metric that is not positive-definite. The squared length of a 4-vector defined via this metric must then be an important invariant independent of the orientation or the velocity of the frame. Indeed, for the 4-vector $P_\mu$this is the squared mass m^2 of the particle, and it is one of the two invariant labels used in specifying the representation. The other label is the squared length of another 4-vector called the Pauli-Lubanski vector. It then follows from the algebra of the group that this squared length takes on values $s(s+1)$ and that in contrast to m^2, which assumes continuous values, s can only be zero, or a positive integer, or half a positive odd integer. The unitary representation of the Poincaré group for a particle of mass m and spin s provides its relativistic quantum mechanical wave function. The equation of motion the wave function must obey also comes with the representation; it is the Bargmann-Wigner equation for that spin and mass. The procedure of second quantization then naturally promotes the wave functions to quantized field operators, and in a sense demotes the particles to quanta created or destroyed by these operators. Pauli's spin-statistics theorem, based on a set of very general requirements such as the existence of a lowest energy vacuum state, the positivity of energy and probability, microcausality, and the invariance of the laws of Physics under the Poincaré group, leads to the result that the only acceptable quantum conditions for field operators of integer-spin particles are commutation relations, while those corresponding to half-integer spin must obey anticommutation relations. The standard terms for the two families of particles are bosons and fermions, respectively. The PEP, or the impossibility of putting two electrons into the same state, is now seen to be the result of the anticommutation relation between electron creation operators: to place two fermions in the same state, the same creation operator has to be applied twice. The result must vanish, since the operator anticommutes with itself.

We have thus seen that the symmetries of space-time are reflected in the fields which are representations of the symmetry groups; a quantum mechanical recipe called quantization then turns these fields into operators capable of creating and destroying quanta (or particles, in more common parlance) at all space-time points. Actually, the framework we have described only suffices to describe "Free fields" which do not interact with each other. In order to incorporate interactions, one has to resort to another kind of symmetry called gauge symmetry, which operates in an "internal" space attached to each point of space-time. While the identity of masses and spins of, say, electrons can be attributed to space-time symmetries, the identities of additional quantum numbers such as charge, isospin and "color" can only be explained in terms of the representations of these gauge groups.

5. The answers:

We are now in a position to relate the questions of sections 2 and 3 to RQFT. Electrons are identical because they are created by the same electron quantum field. Since this field embodies Poincaré invariance, it operates in the same way at all space-time points and in different Lorentz frames; thus the electrons created by it must always have the same spin, mass and charge. The same obviously holds for other fermions such as the quarks, which are first bound together by bosonic fields called gluons to form protons and neutrons. These nucleons then combine to form atomic nuclei through Van der Waals-like residual gluonic forces. At suitable densities and temperatures, such as $300,000$ years after the Big Bang, hydrogen and helium nuclei can bind electrons by photon fields and form atoms. Heavier atoms result from processes of stellar evolution and collapse. Atoms chemically bond with other atoms, producing ever more complex molecules and, finally, intelligent life which tries to understand its environment. Every step in the dynamical processes outlined above involves not only the forces, but also the constraints imposed by the commutation and/or anticommutation relations of the fields. The stability of matter, in particular, is in large measure due to the PEP. Free neutrons undergo β-decay with a lifetime of about ten minutes, but live practically forever in stable nuclei because the proton that would result from the decay cannot move into energetically available but already occupied proton states. The arrangement of electrons in atoms and the formation of molecular bonds, both ionic and covalent, is dictated by the PEP. The near-incompressibility of most condensed matter, the stability of white dwarf and neutron stars, are among its macroscopic consequences. These qualitative statements are supported by rigorous arguments and computations [16]

To recapitulate: in section 2, we raised some questions about the origins of common names (or, equivalently, the Platonic concept of Universals) and verbs (Q1 and Q2)), the idea of whole numbers (Q3), and our perception of regions of space as “full” and “empty” (Q4). Q5, which was related to Q4, concerned the relation between “being” and “nothingness”, the former in the specific example of, an electron, and the latter, the vacuum. In section 3, we gave partial answers based on Non-Relativistic and then Relativistic Quantum Mechanics, supplanted by the PEP, which had to be introduced as an additional, empirically-based input. The answers were partial in the sense that while, for example, the identity of the energy levels in two hydrogen atoms could be explained, the identity of all electrons, or all protons, had to be assumed as a starting fact. In relation to question Q5, we gave an example of a theory where the vacuum is represented by a full medium, while holes in the medium are detected by experimenters as positively charged versions of the electrons. Finally, in section 4, we saw that the identity of fundamental particles is a direct consequence of the symmetries of space-time and the quantum conditions in RQFT. Furthermore, the PEP was revealed to be nothing but the quantum conditions for fermion fields; hence we can now quite accurately pinpoint the fundamental cause of death when people jump off the Bosphorus bridge: The killer is the equal-time anticommutation relation of the quantized electron field. We hope to have convinced the reader that RQFT, far from being a theory limited to explaining esoteric subatomic phenomena, shapes both the world we directly experience and our most fundamental concepts about it.

So far we have limited ourselves to a picture in which a disembodied intelligence acquires ideas about the external world as a result of its experiences. Let us now make assumption, by no means universally accepted by philosophers, that all mental events are rooted in biochemical brain events, and delve into the actual workings of the human brain on the basis of that assumption. While brain science is in its infancy, one of the known facts is that electrical signals are sent among nerve cells along channels through variations in the concentrations of Na^+, K^+ and Cl^- ions inside and outside the channels [17]. Given that the code for constructing the brain is encoded in the DNA which we argued owes it stability and repeatable features ultimately to RQFT, and that the same holds for the ions used in the signalling, we see that human minds, great or not, think alike not just because of the similarities in the data they receive from a RQFT-shaped environment, but because they themselves are also ultimately shaped by RQFT.

6. A truly classical universe?

Let us now try to imagine a Universe in which Planck's constant h is not merely small compared to macroscopic actions or angular momenta, but truly and strictly zero. The laws of classical Physics that can be derived formally from their quantum mechanical versions by focusing on expectation values and letting h go to zero (even General Relativity, whose quantum origins are not yet completely understood, has a tentative microscopic version in String theory) will now, for the sake of argument, be regarded as being "exact" and "fundamental". These laws consist of (i) Einstein's field equations, with the stress-energy tensors of the electromagnetic field and of massive particles on the right-hand side, (ii) geodesic equations for the motion of particles (ignoring the question of how such particles may come into being within classical physics) in gravitational and electromagnetic field backgrounds and (iii) Maxwell's equations in curved space for electromagnetic fields, with charge-current sources again on the right-hand side. Such a system of equations has well-known problems such as runaway solutions and infinite self-energies for particles, so in a sense it is not entirely logical to pursue this line of thought. Nevertheless, let us temporarily ignore these objections in order to sketch the qualitative aspects of the physical environment the equations predict. A basic feature of such a universe must be the loss of energy of accelerating matter through electromagnetic or gravitational radiation. The slowed-down masses with or without charges will then tend to clump together under attractive gravitational and electromagnetic forces. Unlike in quantum physics, there will be no counterbalancing effects such as the HUP or the PEP, and collapses are bound to occur even if they may be delayed by initial velocities and angular momenta. The only imaginable result is a collection of Black Holes, each one of which has angular momentum, mass and charge unlike any other. There being no Planck's constant, such Black Holes cannot evaporate via Hawking radiation. The initial conditions will then determine whether the Black Holes will eventually diverge from each other in an open universe or all will collapse into a single hole. Provided it is physically possible at all, this is the likely actual picture of Nature envisaged by "Classical Physics", but it is clearly does not resemble the world we are a part of.

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References

[1] Reichenbach, H. "Philosophic foundations of Quantum Mechanics", Univ. of California Press (1965); Heisenberg, W. "Physics and Philosophy", Harper Torchbooks (1966). .

[2] Zurek, W.H., Physics Today**44**(Oct. 1991), p.36; Giulini, D.,Joos, E., Kiefer, C., Kupsch, J., Stamatescu, I. and Zeh, H.D. "Decoherence and the appearance of a classical world in Quantum theory", Springer-Verlag (1966).

[3] Leibniz, G.W., Correspondence with Burcher de Volder (1698-1706), in "The Cambridge dictionary of Philosophy", Audi, R. (ed.), Cambridge University Press (1995). .

[4] Plato, in "Phaedo", transl. by R. Hackforth, Cambridge University Press (1955).

[5] Frege, G. "Die grundlagen der Arithmetik, Jena, (1884); Russell, B. "History of western Philosophy", Unwin University Books (1961), p. 784.

[6] Russell, B. and Whitehead, A.N., "Principia Mathematica", Cambridge University Press (1910-1913).

[7] Whittaker, E. "A history of the theories of Aether and electricity", Vol.1, Nelson, London (1958), p. 203.

[8] Schrodinger, E. "What is life", Cambridge University Press (1944).

[9] Feynman R. P., Nobel Lecture "The development of the space-time view of Quantum Field Theory", Science **153** p. 702 (1966); Stueckelberg,E.C.G., Helv. Phys. Acta **14** p. 588 (1941).

[10] Einstein, A. and Infeld, L., "The evolution of Physics", Cambridge University Press (1938).

[11] Dirac, P.A.M., "Principles of Quantum Mechanics", Oxford University Press, p.391 (1989).

[12] Pauli, W., Phys. Rev.**58** 716 (1940).

[13] Bargmann, V. and Wigner E.P., Proc. Nat. Acad. Sci.(USA)**34** p.21 (1948).

[14] Weyl, H. "Symmetry", Princeton University Press (1952).

[15] Clagett, M. "The science of mechanics in the Middle Ages", Madison, Wisc., Univ. of Wisconsin Press (1959); Clagett, M. "Greek sciences in antiquity", Part II, New York (1955); Nasr, S. H., "Science and civilization in Islam", Harvard University Press (1968).

[16] Lieb, E. and Thirring, W., Phys. Rev. Lett.**35** p.687 (1975); Lieb, E. "The stability of matter", Rev. of Mod. Phys.**48** p. 553 (1976); Lieb, E. "From atoms to stars", 1989 Gibbs Lecture, Bull. Amer. Math. Soc. **22** p.1 (1990).

[17] Penrose, R. "The Emperor's new mind", Oxford Univ. Press p.391 (1989).