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AN ESSAY ON THE FOUNDATIONS OF PHYSICS* †

H. Pierre Noyes

Stanford Linear Accelerator Center
Stanford University, Stanford, California, 94305

Physics was a minor branch of philosophy until the seventeenth century. Galileo started "physics" in the contemporary sense. His emphasis on mathematical deduction in contrast to the "observational" methodology of Aristotle was one of many criticisms brought against him by his enemies established in the universities. This evoked from him the comment that he had spent more years in the study of philosophy than months in the study of mathematics. Some later commentators have also criticized his *a priori* approach to physics without appreciating his superb grasp of the experimental method which he created, – including reports of his experiments that still allow replication of his accuracy using his methods. He firmly based physics on the *measurement* of *length* and *time*, and established the uniform acceleration of bodies falling freely near the surface of the earth.

A century later, Newton entitled what became the paradigm for "classical" physics *The Mathematical Principles of Natural Philosophy*, recognizing the roots that physics has in both disciplines. He also was a superb experimentalist. To a greater extent than Galileo, Newton had to create "new mathematics" in order to express his insight into the peculiar connection between experience, formalism, and methodology that still remains the core of physics. To length and time, he

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added the concept of *mass* in both its inertial and its gravitational aspect, and tied physics firmly to astronomy through universal gravitation.

The connection between natural philosophy and religion was of importance to both of them. Galileo held (and paid a price for his faith) that God could not have created a world that said one thing through nature (His handiwork) and the reason He had given His creatures and another through His revelations to the community of the faithful. Partly because of the trouble this belief got him into with the Inquisition (which had reflections and anticipations in Protestant communities), subsequent scientific philosophy has erected a barrier between faith and reason. Perhaps because of his unorthodox Arian theology, Newton shied away from those issues in his scientific work. But he still left a role for the Creator in his natural philosophy, in contrast to the rationalist tradition that is associated on the continent with Descartes. The residue of these questions is still with us in terms of the rejection of "action at a distance" by the continental tradition, the problem of distant simultaneity raised by Einstein (and for some dogmatically solved by him) and the understanding of the recently measured "supraluminal correlations". These seem to violate "Einstein locality" if one follows Bell in his attempted resolution of the Bohr-Einstein debate.

It is often thought that Einstein's special relativity rejects the concept of absolute space-time, until it is smuggled back in through the need for boundary conditions in setting up a general relativistic cosmology. But indeed the concept of the homogeneity and isotropy of space used by Einstein to analyse the meaning of distant simultaneity in the presence of a limiting signal velocity in fact is very close to Newton's absolute space and time. What Einstein shows is rather that it is possible to use local, consequential time to *replace* this concept. This was pointed out to me by David McGoveran[1] in the context of our fully finite and discrete approach to the foundations of physics, and our derivation of the Lorentz transformations without using the concept of continuity. This same analysis shows that in a discrete physics, the universe has to be multiply connected, and the space-like separated "supraluminal" correlations which are predicted by quantum mechanics and recently demonstrated experimentally to the satisfaction of many physicists are to be anticipated not only for spin but for other quantized degrees of freedom.

Nineteenth century physics saw the triumph of the electromagnetic field theory, but was still firmly based on arbitrary units of mass, length and time; it provided no way to question *scale invariance.* Quantum theory and relativity were born at the beginning of this century, but quantum mechanics did not take on its current form until nearly three decades of work had passed. Although one route to quantum mechanics (that followed by deBroglie and Schroedinger) started from the continuum relativistic wave theory, the currently accepted form breaks the continuity by an interpretive postulate due to von Neumann sometimes called "the collapse of the wave function". Criticism of this postulate as conceptually inconsistent with the time reversal invariant continuum dynamics of wave mechanics has continued ever since, although somewhat muted for a while by the near consensus of physicists that Bohr had "won" the Einstein-Bohr debate and the continuing dramatic technical successes of the theory. But scale invariance is gone because of the quantized units of mass, action and electric charge. These specify in absolute terms what is meant by "small" while the expanding universe and event horizon specify what is meant by "large".

For a while it appeared that reconciliation between quantum mechanics and special relativity would resist solution, since the uncertainty principle and second quantization of classical fields gave an infinite energy to each point in space-time! During (Tomonoga) and after (Schwinger and Feynman) World War II, formal methods were found to manipulate away these infinities and obtain finite predictions in fantastically precise agreement with experiment. Recently the non-Abelian gauge theories have made everything calculated in the "standard model" finite. Weinberg recently asserted at the Schroedinger Centennial in London that there is a practical consensus – but no proof – that second quantized field theory is the *only* way to reconcile quantum mechanics with special relativity. However he also pointed out that the finite energy due to vacuum fluctuations is then

10^{120} too large compared to the cosmological requirements; the universe should rap itself up and shut itself off almost as soon as it starts expanding. Even if one is willing to swallow this camel, there is no clear way to include strong gravitational fields in the theory. So continued attention to foundations seems fully justified.

The approach my collaborators [Amson, Bastin, Etter, Gefwert, Kilmister, Manthey, McGoveran, Parker-Rhodes (dec.), Stein] and I have been pursuing[2–5] starts with a commitment to finiteness, discreteness, finite computability and absolute non-uniqueness as an obvious starting point for the construction of the unique, discrete, irreversible, non-local and yet indivisible events of quantum mechanics. We reject the continuum and unbounded recursion from the outset, using constructive mathematics, and more significantly modern computer science, as the basis for our representational framework. We show that by basing physics on a growing universe of bit strings generated by a simple recursive algorithm we can construct quantum events necessarily exhibiting 3-momentum conservation and periodic interference, a limiting velocity and the Lorentz transformations for these quantum events in our discrete and *necessarily* 3+1 dimensional space-time, the conserved quantum numbers of the first generation of the standard model for quarks and leptons and a flat space "big bang" cosmology. The combinatorial hierarchy of Amson, Bastin, Kilmister and Parker-Rhodes ($2^2 - 1 = 3 \Rightarrow 2^3 - 1 = 7 \Rightarrow 2^7 - 1 = 127 \Rightarrow 2^{127} - 1$) which *terminates* at the fourth level[6,7] is a direct consequence of the construction. Our rules of procedure and epistemological framework (which include the contemporary practice of high energy particle physics) then justify the interpretation (to order 1/137)that $\hbar c/e^2 = 137, \hbar c/Gm_p^2 = 2^{127} + 136 = 1.7 \times 10^{38}$. We can also claim the Parker-Rhodes result[8] $m_p/m_e = 1836.151497...$, although its extreme accuracy is still something of a puzzle. We are now working out the details of the coupling schemes which the model forces on our quarks and leptons. We are sure that just how weak-electromagnetic unification is achieved will differ in detail from the standard model, since we have no renormalization problem and hence no need for the Higgs mechanism. This is bound to produce observable consequences and, hopefully, a decisive test.

The current era in high energy particle physics, in computer science where parallel processing creates non-determinism born of computational complexity and impoverished representational power and in superconducting technology where macroscopic systems might exhibit phenomena similar to the peculiar behavior of "Schroedinger's cat" has set the stage for renewed interest in foundational studies in these fields. The extant traces of the very early stages of the big bang seem to be the only place to test many modern theories of grand unification, supergravity, superstrings, ... Whether our own commitment to a fully discrete foundational basis will prove fruitful for physics remains to be seen. We have already connected current thinking in computer science and discrete mathematics to the origin of non-commutativity, limiting velocities and distant synchronization in physics. If work along this line succeeds, we are in for what Kuhn would call a "paradigm shift" of major proportions. Even if the conventional approach turns out to come closer to the way future physics develops, it is bound to produce a "new synthesis" of even grander scope than the "Newtonian Synthesis" of three centuries ago. A Center for Foundational Studies clearly could have significant impact on the cross-disciplinary aspects of this development.

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