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THE MEASUREMENT PROBLEM IN PROGRAM UNIVERSE*

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ABSTRACT

The "measurement problem" of contemporary physics is in our view an artifact of its philosophical and mathematical underpinnings. We describe a new philosophical view of theory formation, rooted in Wittgenstein, and Bishop's and Martin-Lōf's constructivity, which obviates such discussions. We present an unfinished, but very encouraging, *theory* which is compatible with this philosophical framework. The theory is based on the concepts of counting and combinatorics in the framework provided by the combinatorial hierarchy, a unique hierarchy of bit strings which interact by an operation called discrimination. Measurement criteria incorporate $c, \hbar$ and m_p or (*not* " and") G. The resulting theory is discrete throughout, contains no infinities, and, as far as we have developed it, is in agreement with quantum mechanical and cosmological fact.

1. PARTICIPATING IN A RESEARCH PROGRAM

Physics is an ongoing research program. A *research program*[1] contains two non-separable parts: Theory and Measurement (Experiment). A research program is in equilibrium when it forms an ongoing (complete) *practice*. In equilibrium there is stability both between knowledge of meaning and knowledge of facts

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and between theory [in our sense] and measurement. As Goodman[2] has said "A rule is amended if it yields an inference we are unwilling to accept; an inference is rejected if it violates a rule we are unwilling to amend." Only when these conditions are satisfied do we have a complete practice, — a research program.

A research program is constituted by a theory part, providing knowledge of meaning, and a computational part, providing knowledge of fact. There is a certain order in which a research program is to be formulated. To engage in a research program one has first to *formulate* the mathematical part of the theory constituting the formal criteria of the theory. These criteria express the information needed to compute facts. However, this is only a part of the theory. Also, one has to formulate the a-formal (measurement) criteria. Only now is the theory complete; it shows *what to do* when one uses the criteria in order to measure facts. A research program shows equilibrium between measurement facts and criteria used. If this is the case, then the research program is in corroborative equilibrium, to use Popper's terminology. Failure of the research program reflects falsification of the task at hand: the formulation of a correct theory.

To formulate a theory is to create the criteria. This is done in virtue of *judgments.* A judgment can be understood either as an act of knowledge or as an object of knowledge. It is important to note that one *formulates* the criteria of the theory. To formulate a criterion is to engage in an act of knowledge. An act of judgment is complete *only* when the expression which is the output of the act is coded. Thus coded criteria express judgments (rules). The criteria are necessarily correct as such and an incorrectly (ill-) formed criterion is meaningless. A criterion is ill-formed if it does not express the information needed to compute a fact. The formulated (well-formed) criteria are, when used, used as objects of knowledge: *objects are constructions.* Thus a *theory* in the sense we use the notion is a theory of constructions. A theory of constructions is *complete* in the sense that the information necessary in order to compute facts (e.g. by computer) is completely provided by the theory.

Existing quantum mechanics, having an additional "measurement theory" which has never been formulated in a satisfactory way, is, in the words of Wheeler a *law without law.*[3] . The task we confront is to formulate a complete quantum theory incorporating measurement. A complete quantum theory must take the form of a theory of constructions. For us *the notion of computation replaces the old dichotomy of Quantum Theory and an additional Measurement Theory.*

In the context we establish the "measurement problem" does not have a separate locus. The overall success of the *program*, or any specific application of it under specific circumstances, can be thought of as a "measurement". The specific problems that arise when some version of quantum theory is embedded in an *a priori* space-time continuum simply do not arise for us. There is no demarcation between "participator" and the *research program* itself. Objectivity is achieved by the explicit recognition of the engagement of the participator, along the lines suggested by Wheeler[3], in the research program which constructs both the mathematics used and the connection between the theory and laboratory experiment. The philosophical position adopted has been discussed by one of us (CG) elsewhere[4] .

The mathematical expressions such as $0, 1, +_2, =, ...$ which we introduce stand for primitive recursive functions; when combined they form *programs* which give the information needed for their own evaluation[5] . We regard combined (well-formed) mathematical expressions as programs. They are programs which give information concerning their own evaluation. When engaged in formulating a theory (of constructions) we are to formulate (evaluate, recover) the person program. By a person program is to be understood the formulated theory which functions like an instruction manual. The person program provides the information concerning *what to do* in order to engage in measurements. We are to provide instructions concerning what to do in order to terminate the task expressed by the program. By engaging in formulating the theory in order to recover the rules one *evaluates* a program and provides the necessary information a human (using a person program), or when transformed, a computer (using a computer program) needs in order to participate in terminating the computational tasks of relativistic quantum mechanics. By evaluating such programs one can show that the mathematical expressions (programs) used are self-explanatory (complete) vis-a-vis meaning. In this way we ground our theory in the constructive mathematics of Bishop[6] and certain ideas of Martin-Lõf[7] .

We present here a research program whose aim is to yield a complete relativistic quantum theory characterized by unique discrete and indivisible events which are globally correlated but cannot be used to transmit supraluminal signals.

2. CONSTRUCTING A BIT STRING UNIVERSE

We introduce natural numbers n by the usual rule that $n + 1$ is the successor of n and that "1" as a natural number has no precursor (cf. Ref. 5 for a rigorous primitive recursive definition of the natural numbers and the successor operation). Including the symbol "0" by bitwise "exclusive or" ($+_2$), we have strings $S^a(NU) = (..., b^a_n, ...)_{NU}$, where $b^a_n \in 0,1$ and $n \in [1,2,...,NU]$, which combine by "XOR" $S^a \oplus S^b \equiv (..., b^a_n +_2 \ b^b_n, ...)_{NU}$ when the symbols "0", "1" are *bits*, and by $S^a \oplus S^b \equiv (..., (b^a_n - b^b_n)^2, ...)_{NU}$ when they are *integers*. We call *either* operation *discrimination*. Calling the null string $0_N \equiv (0, 0, ..., 0)_N$, for a, b, c distinct we have the symmetric relation for any discrimination $S^a \oplus S^b \oplus S^c = 0_N$. We also define the anti-null string $1_N \equiv (1, 1, ..., 1)_N$ and the "bar" operation $\bar{S}^a(N) \equiv 1_N \oplus S^a(N)$.

The basic algorithm for our construction (Program Universe) generates a growing universe of bit strings $\mathbf{U}(SU, NU)$, where SU specifies the number of strings and NU the length at each stage of the construction. All strings are different by construction and are called $U[i], i \in 1, 2, ..., SU$. The program starts by invoking the operator R which provides either the output $r = 0$ or the output $r = 1$ with equal probability to assign $U[1] := R, U[2] := \bar{R}$, and setting $SU := 2, NU := 1$. Here and below we use the conventional computer notation: ":=" means value replacement. Manthey[8] gives an explicit construction of R using the primitive operation "flip-bit", a construction which relies solely on the non-determinism born of unsynchronized communication over a shared memory. We then invoke the operation $PICK$ which selects any one of the SU unique strings currently in the universe with probability $1/SU$; it can be constructed from R.

Entering at $PICK$, we take $S_1 := PICK; S_2 := PICK; S_{12} := S_1 \oplus S_2$. If $S_{12} = 0_{NU}$, we have had the bad luck to pick the same string twice, and revert to picking S_2 until we pass this test. We then ask if S_{12} is already in the universe. If it is not we adjoin it $\mathbf{U} := \mathbf{U} \cup S_{12}, SU := SU + 1$ and return to $PICK$. If S_{12} is already in the universe we go to TICK. This simply adjoins a bit (via R), arbitrarily* chosen for each string, to the growing end of each string, $\mathbf{U} := \mathbf{U} \| R$,

* When we use the terms "arbitrary" or "arbitrarily" in what follows, we mean "not due to any finite, locally specified algorithm". These arbitrary numbers are to be contrasted to the "random" numbers encountered in a continuum context which no global or local algorithm will suffice to specify. We are indebted to David McGoveran for these definitions.

$NU := NU + 1$, and returns us to $PICK$; here "$\|$" denotes string concatenation. It follows that *any* TICK arises from one of two possibilities: $S^a \oplus S^b \oplus S^c = 0_{NU}$, which we call an *elementary 3-event*, or $S^a \oplus S^b \oplus S^c \oplus S^d = 0_{NU}$ which we call an *elementary 4-event*. These events are identified below as the unique and indivisible events of quantum theory.

The discrimination operation on a set of strings has the important property of *closure*, first noted in our context by John Amson[9] . Given two distinct (in this context *linearly independent* or l.i.) non-null strings a, b, the set $\{a, b, a \oplus b\}$ *closes* under discrimination since any two will yield the third. We call this a *discriminately closed subset* (DCsS), and by observing that the singleton sets $\{a\}$, $\{b\}$ are closed, we see that two l.i. strings generate 3 DCsS's. Given a third l.i. string c, we can generate $\{c\}$, $\{b, c, b \oplus c\}$, $\{c, a, c \oplus a\}$, and $\{a, b, c, a \oplus b, b \oplus c, c \oplus a, a \oplus b \oplus c\}$ as well. In fact, given j l.i. strings, we can generate $2^j - 1$ DCsS's because this is the number of ways we can choose j distinct things one, two,... up to j at a time.

In order to construct the combinatorial hierarchy[10] from the DCsS formed from strings we invoke[11] a mapping operation which requires that each set of strings composing the DCsS's of the lower level be the only eigenvectors of a non-singular square matrix of bits which is l.i. of all the other mapping matrices at that level. These matrices are then rearranged as strings and the process is repeated. In this way one generates the sequence $(2 \Rightarrow 2^2 - 1 = 3), (3 \Rightarrow 2^3 - 1 = 7), (7 \Rightarrow 2^7 - 1 = 127), (127 \Rightarrow 2^{127} - 1 \simeq 1.7 \times 10^{38})$ mapped by the sequence $(2 \Rightarrow 2^2 = 4)$, $(4 \Rightarrow 4^2 = 16)$, $(16 \Rightarrow 16^2 = 256)$, $(256 \Rightarrow 256^2)$. The process terminates because there are only $256^2 = 6.5536 \times 10^4$ l.i. matrices available to map the fourth level, which are many too few to map the $2^{127} - 1 = 1.7016... \times 10^{38}$ DCsS's of that level. If one starts with strings of length 3 or 4, the construction terminates at the second level; these two possibilities are contained in the initial sequence. Strings of length 5 or greater give DCsS which cannot be mapped. Hence the combinatorial hierarchy with four levels is *unique*, a point discussed in more detail by John Amson[9].

The numerical result gives immediately two of the basic scale constants of physics, since the elements in play at level 3 define the cardinal $3 + 7 + 127 = 137 \simeq \hbar c/e^2$ and level 4 the cardinal $2^{127} + 136 = 1.7016... \times 10^{38} \simeq \hbar c/Gm_p^2$. This connection to physics is not compelling for most people who encounter the scheme for the first time. The theory presented here is the latest attempt of many[11] to convert this initial insight into a rigorous physical theory.

It can be shown[11] that Program Universe necessarily generates some representation of the basis strings for the combinatorial hierarchy in the initial strings of length $N_L \geq 139$ which are unchanged by subsequent TICKs and which by discriminate closure generate precisely $2^{127} + 136$ unique strings of that length representing all elements of the combinatorial hierarchy. Hence, once this closure has been achieved, for any string in the universe of length $NU = N_L + N$ we can call the initial part of the string of length N_L the *label* and the remainder of the string, of length N, the *address*. Clearly the number of address strings and the length of each string for each label will continue to grow. We call this property of the program *label invariance*.

We do not envisage this computer program as a "big computer in the sky" which by some means we might be able to access directly. We use the program primarily to insure that all formal criteria used in our construction can in practice lead to computable facts.

2. SCATTERING THEORY

At this point we introduce the basic *counter paradigm* on which we will found our *a-formal measurement criteria* – the third of our four steps in constructing a research program according to the schema discussed above. We start from any unique macroscopic (laboratory or natural) event called the "firing of a counter". Our paradigm is: *any* **elementary event**, *under circumstances which it is the task of experimental particle physics to specify and investigate, can lead to the firing of a counter.*

The way in which we connect our bit string universe to the physical parameters encountered in scattering theory and employed in laboratory practice is to use the label strings to define quantum numbers which are conserved in events, and address strings to define relativistic velocities associated with these quantum numbers. Consider first the quantum numbers we can define for strings of even length n_ℓ. For simplicity we consider only strings of length two and four, and concatenations of them. We define our quantum numbers in such a way that the operation $\bar{S}(n) = 1_n \oplus S(n)$ changes the sign of all quantum numbers, and that the strings 0_n and 1_n have the value zero for all quantum numbers. Then for strings of length 2 written as $(b_1 b_2)$ we can have the quantum number $q_0 = b_1 - b_2$, which takes on the values $0, \pm 1$, and for strings of length four written as $(b_3 b_4 b_5 b_6)$ we can have the three quantum numbers $q_1 = b_3 - b_4 + b_5 - b_6$, $q_2 = b_3 + b_4 - b_5 - b_6$ and $q_3 = b_3 - b_4 - b_5 + b_6$ which take on the values $0, \pm 1, \pm 2$. We identify the "bar" operation that changes the sign of all quantum numbers as the operator that in conventional theory changes the quantum numbers for a "particle" into those for the corresponding "anti-particle". It is then possible to identify the label discriminations involved in elementary events as related to a situation in which all quantum numbers add to zero: $q_a + q_b + q_c = 0$ for 3-events and $q_a + q_b + q_c + q_d = 0$ for 4-events. Once we have established a *context dependent* "direction" for the "flow" between TICK-separated events, these elementary possibilities will allow us to consider also the situation in which by changing a particle to an anti-particle (which will include reversing its velocity- see below) the quantum numbers will be conserved in processes such as $a + b \rightarrow \bar{c}$, $b + c \rightarrow \bar{a}$, $c + a \rightarrow \bar{b}$, and $a + b \rightarrow \bar{c} + \bar{d}$, $a + c \rightarrow \bar{b} + \bar{d}$, $a + d \rightarrow \bar{b} + \bar{c}$. Thus our theory allows us to define "crossing" in a manner familiar from the Feynman diagrams of S-matrix theory.

In order for this to work, we must, as already noted, define velocities in such a way that the "bar" operation reverses their sign, which turns out to be easy. For any address string $A^w(N)$ in the ensemble labeled by $L^w(n_\ell)$ we first define the parameter $k^w = \Sigma_{n=1}^{N} b_n^w$, which has the advantage of making our theory independent of the specific order in which the bits occur in the strings, and then the parameter $\beta_w = \frac{2k_w}{N} - 1$ which is a signed rational fraction in the set $[-1, -\frac{(N-1)}{N}, ..., +\frac{(N-1)}{N}, +1]$. This definition meets the requirement that velocities reverse sign under the "bar" operation. It has the further consequence that the dimensional unit in terms of which velocities are related to laboratory measurement can be taken to be the limiting velocity c. Because of label invariance, we can also associate some numerical parameter m_w with each unique label; the parameters m_w need not be unique! Any elementary 3-event is then specified by six numerical parameters $m_a, m_b, m_c, \beta_a, \beta_b, \beta_c$. We define $\gamma^2 = \gamma^2\beta^2 + 1$ and six new parameters $E_w = m_w\gamma_w$ called "energies" and $p_w = \gamma_w\beta_w m_w$ called "momenta", which makes $E_w^2 - p_w^2 = m_w^2$ independent of β. Hence our 3-event can also be described by $E_a, E_b, E_c, p_a, p_b, p_c$. We further assume that all masses $m_w \geq 0$ and that $\gamma = +\frac{1}{\sqrt{1-\beta^2}}$ making all energies positive.

The problem we now encounter is that the values of β defined by discrimination do not in themselves define the kinematics of four-momentum conserving classical relativistic particulate "collisions" in 3+1 dimensional energy-momentum space. However we are constructing a finite particle number quantum scattering theory, and *not* classical particle kinematics. The continuum version of such a theory has recently been presented[12] . It was found that in order to obtain a theory which guarantees unitarity, clustering, Lorentz invariance and the proper connection to the non-relativistic Faddeev equations, it was necessary to abandon the conventional 4-momentum notation $\vec{P} = (E, \underset{\sim}{p})$, $\vec{P}_a \cdot \vec{P}_b = E_a E_b - p_a p_b cos\theta_{ab}$ and use instead unit *4-velocities* $\vec{u} = (\gamma, \gamma\underset{\sim}{\beta})$ with $\vec{u} \cdot \vec{u} = 1$; the masses are then parameters rather than dynamical variables. Clearly this is consistent with the way masses have been assigned to labels above. Then we can associate a four-vector $\vec{P}$ with a four-velocity $\vec{u}$ and a parameter M by defining $\vec{P} = M\vec{u}$ with $\vec{P} \cdot \vec{P} = M^2$ independent of the velocity. Then our elementary events can be completely described internally in terms of the parameters $M_{ab}^2 = (\vec{P}_a + \vec{P}_b) \cdot (\vec{P}_a + \vec{P}_b)$ (and cyclic); we define "angles" algebraically via the algebra of the trigonometric functions without geometrical implications, as is appropriate in a digital theory.

In a theory of this type only the scalar parameters M_{ab} are allowed to go "off shell" (i.e. $M_{ab}^2 \neq m_c^2$), and mass is defined by 3-momentum conservation: $m_a \underset{\sim}{u}_a + m_b \underset{\sim}{u}_b + M_{ab} \underset{\sim}{u}_{ab} = 0$ with the magnitude of β_{ab} set equal to the magnitude of $\beta_c = \frac{2k^c}{N} - 1$ as specified by the discrimination which causes the event. This keeps all angles physical and tells us that $M_{ab}^2 - (m_a + m_b)^2$ is bounded by $2m_a m_b[\gamma_a \gamma_b(1 \pm \beta_a \beta_b) - 1]$. This way of meeting the "off-shell" problem allows 3-momentum to be conserved, and define mass, whatever values of the velocities result from the discriminations causing individual events.

Starting from the fact that in the absence of further information the probability of a string with $k = \frac{N}{2}(1+\beta)$ "1" 's correspond to the value β is $N!/2^N([\frac{N}{2}(1+\beta)]!)([\frac{N}{2}(1-\beta)]!)$ it can be shown that a "particle" (i.e. an ensemble of address strings whose label string specifies a mass and set of quantum numbers) in two situations connected by discrimination will have a range of energies centered on $E = \gamma mc^2$ and E' respectively is strongly peaked about the situation with $E = E'$. We represent this situation, the product of two probabilities normalized to unity when $E = E'$, by $\frac{\eta^2}{(E-E')^2+\eta^2}$. Here η is a positive quantity which becomes arbitrarily small when the length of the address strings is large. This allows us to arrive at the "propagator" $G^{\pm} = \frac{\pm i\eta}{(E-E')\pm i\eta}$ representing the probability amplitude for a "particle" making such a an "off-shell" transition; Here the $\pm i$ is introduced to keep tract of the ordering context referring to whether the "particle" is "outgoing" or "incoming". Summing over values allowed by 3-momentum conservation in the ("asymptotic") context of a large sequence of TICK's then tells us that 4-momentum will be conserved. This is how we describe a "particle" getting from here to there in a macroscopic context. Note that our basic concepts are only discrete events and statistics; for us *through chance, events and the void suffice.*

We now can envisage a macroscopic situation in which two particles with masses m_a and m_b start from 4-momenta $\vec{P}_i^a, \vec{P}_i^b$ and end with $\vec{P}_f^a, \vec{P}_f^b$ which satisfy the kinematic constraints for free particle scattering. We call this a (two-particle elastic) *scattering event*, and ask how to compute the probability amplitude for its occurrence. Consider the case when there are two intermediate elementary 3-events in one of which particle a changes its 4-momentum from $\vec{P}_i^a$ to $\vec{P}_f^b$ and an off-shell particle with mass μ_{ab} appears, while in the second this particle disappears and particle b changes its 4-momentum from $\vec{P}_i^b$ to $\vec{P}_f^b$. Because of our conservation laws and boundary conditions, $E_i = E_i^a + E_i^b = E_f^a + E_f^b = E_f$, and the energy of the off-shell particle $\epsilon_{ab} = \sqrt{\mu_{ab}^2 + (\underset{\sim}{p}_a - \underset{\sim}{p}_b)^2}$ is also the inverse propagator. Assume that the probability of the first 3-event is g_a and of the second g_b (numbers we will eventually have to compute). Then since we must multiply the probabilities for the initial and the final events, including the production and disappearance of the propagator - since we must consider all possibilities consistent with our boundary conditions - the scattering amplitude for this process is $t_{ab}^{Born} = g_a g_b / (\mu_{ab}^2 + (\underset{\sim}{p}_a - \underset{\sim}{p}_b)^2)$. We have thus derived the familiar "Born approximation" in an unfamiliar way. From here on we can follow the development of the finite particle number relativistic and unitary quantum scattering theory [12].

3. ELEMENTARY PARTICLE QUANTUM THEORY

For any string with $\beta = \pm 1$ it can be shown that producing an address string with any other value by an event has zero probability, so assigning zero mass to such strings will insure that this does not change. In particular we assign zero mass to the anti-null string, which changes particle to antiparticle, or via crossing allows a particle to pass through an event without changing its quantum numbers. When we consider only levels 1,2, and 3 this label will occur with probability1/137, so for this situation our Born amplitude becomes $\frac{(1/137)}{E^2 sin^2(\theta/2)}$, the amplitude for Rutherford scattering (with $e^2/\hbar c = 1/137$). Our integral equations sum a very large number of such scatterings and produce, macroscopically, "trajectories" which would be called classically the paths of a particle in a Coulomb field. The poles in these equations define bound states which, in first approximation have the spectrum of the Bohr atom. Thus our theory makes clear contact with familiar laboratory experience. At level 4 the anti-null label which occurs with probability $1/(2^{127}+136)$ gives us, by the same argument, a correct quantum mechanical description of Newtonian gravitational scattering for elementary particles, as needed to explain interference effects between cold neutron beams which follow different gravitational paths.

It remains to connect one particular dichotomous quantum number ("spin") to the momentum-space, and space-time description. We first consider a *part* of the label specified by the $n = 2$ strings $(b_1 b_2)$ and define the quantum number $2h_z = b_1 - b_2$ which has the value $\pm\frac{1}{2}$ for (10) and (01) respectively, and is otherwise zero. We call the remaining quantum numbers q_h. By considering label and address strings separately we can define, in addition to the "bar" operation $AS^w(h_z, q_h; \beta) = S^w(-h_z, -q_h; -\beta)$ the three operators $HS^w(h_z, q_h; \beta) = S^w(-h_z, q_h; \beta)$, $QS^w(h_z, q_h; \beta) = S^w(h_z, -q_h; \beta)$, and $VS^w(h_z, q_h; \beta) = S^w(h_z, q_h; -\beta)$. which do the same job for us as P, C and T in the conventional theory.

We can now connect the sign of h_z to the sign of β by considering a particular class of labeled ensembles, which we call "f-particles", for which at the moment only these two parameters are significant. Referring $f_\pm$ to $h_z = \pm\frac{1}{2}$, we define $f_\pm(\beta)$ by the obvious requirements that

$$Hf_+(\beta) = f_-(\beta),\ Hf_-(\beta) = f_+(\beta);\ Vf_+(\beta) = f_+(-\beta),\ Vf_-(\beta) = f_-(-\beta)$$

This specifies only two distinct situations, which define the *relative* sign of h_z and β as desired.

We now extend our discussion to 3-momentum space by replacing β by $\utilde{\beta}$ in the above expressions making any scattering of such a particle context dependent in terms of the *external* (eg laboratory specified) direction of $\utilde{\beta}$, which our previous discussion of 3-momentum conservation allows us to do. We now can give the variable h a vector significance by tying it to this direction in the following way.

Suppose that there is some direction $\hat{z}$ in our laboratory and define the direction $\underset{\sim}{\beta}$ by requiring that $\underset{\sim}{\beta} \cdot \hat{z} = |\underset{\sim}{\beta}| = \beta_z$ and under this circumstance define $f(\underset{\sim}{h}, \underset{\sim}{\beta})$ as $f_+(h_z, \beta_z)$. If we now scatter this f-particle from any system to some new direction and velocity $\underset{\sim}{\beta}'$, we are only allowed to define it by the two ensembles $f_+(\beta')$ and $f_-(\beta')$. Unless we do this carefully, we will give either an absolute significance to $\hat{z}$ or to $f_\pm$, which our invariance principles do not allow. The situation in fact requires us to make a coherent definition of $\underset{\sim}{h}'$ in terms of the velocities and momenta involved. Once we have done this, we have arrived at a covariant definition of "helicity" or "spin" in our relativistic scattering theory. Since the technical details of working through this familiar problem are complicated, and have recently been reinvestigated in the context of our covariant finite particle number scattering theory[13] we refer the reader to this treatment.

Consider the situation in which two counters a distance $L \pm \Delta L$ apart with no intervening material fire sequentially with a time interval $T \pm \Delta T$ and (after background subtraction) we are insured that a particle of mass m entered the first counter and emerged from the second. In our bit string universe this defines a labeled velocity ensemble with velocity parameter $\beta = L/T$ and velocity uncertainty $\Delta\beta/\beta = \sqrt{(\Delta L/T)^2 + (\Delta T/T)^2}$, in which the strings grow from bit length N_i to bit length N_f consistent with these parameters. If we now think of a bit "1" in any one string added in the interval $N_f - N_i = N$ as a step in the direction that the particle moved and a bit "0" as a step in the opposite direction, the ensemble can be thought of as a biased random walk of N steps of some length ℓ with probability $p = \frac{1}{2}(1+\beta)$ of moving in the direction of the particle motion and $q = \frac{1}{2}(1-\beta)$ in the opposite direction. We can see this by taking the number of "1" 's equal to k and defining $2k = N(1+\beta)$ as before, and recognizing that the binomial distribution we already derived is precisely the distribution for a random walk so defined, an idea we arrived at from Stein's work[14] We introduce Planck's constant into our theory, and hence fix our distance scale, by taking the step length $\ell = hc/E$.

Since $L = \beta cT = N\beta\ell$ and, if each step takes a time δt, $T = N\delta t$, the time per step is $\delta t = \ell/c$. We now define the number of steps n which it takes the peak of the random walk distribution to move one step length, which is $n = \ell/\beta c\delta t$. If the probability distribution is non-uniform along the length (which will always result if we look at the details of the spatial and time resolution of the counters), this distribution will therefore have a *coherence length* $\lambda = n\ell = \ell/\beta c = h/p$ for a pattern moving with velocity βc. From our scattering theory it now follows that the most probable point at which a scattering will occur will have this periodicity; we now have the two periodicities of relativistic deBroglie "waves", with the correct phase and group velocities. From this double slit interference and all the usual consequences of non-relativistic quantum mechanics follow in due course[11].

In our extended treatment[11] we can now show that levels 1, 2 and 3 with 1, 2, and 6 conserved quantum numbers give us the quantum number structure of (1) chiral massless neutrinos, (2) electrons, positrons and vector quanta, and (3) neutrons and protons with the associated mesons "composed" of three quarks or a quark-antiquark pair respectively. These quarks have two flavors and three colors, as do the associated gluons. Thus we have quantum number consistency with the first generation of the "standard model". This pattern repeats in subsequent generations which, by a combinatorial argument should only be weakly coupled to each other. We do not have space here to go into details.

Returning to the general structure, our connection of "velocity" to bit strings brought in the dimensional constant c. Our elementary events allowed us to connect our label-invariant parameters to mass ratios via 3-momentum conservation. Our scattering theory gave us Coulomb and Newtonian gravitational scattering correctly to order (1/137) and tied our bit string universe and quantum events to macroscopic measurement. The mass unit is fixed as the proton mass by the relation $\hbar c/Gm_p^2 = [2^{127} + 136] \times [1 + 0(1/137)]$. Since our masses are defined by momentum conservation, we have no place in our theory for a separate "gravitational mass". Since we have now seen how $c, \hbar$ and m_p (or G) enter our theory, our dimensional connection to the practice of physics is fixed; from now on we must compute everything else. In particular, we take over[11] the Parker-Rhodes calculation[15] for the proton-electron mass ratio $m_p/m_e = 137\pi/[(3/14)[1 + (2/7) + (2/7)^2](4/5)] = 1836.151497...$ in comparison with the experimental value of 1836.1515 ± 0.0005.

5. CONCLUSIONS

The idea of a theory as a *theory of constructions* is valid independent of the "information content" of the theory. In order for a research program to succeed, it must create complete understanding in the way we have developed the theory.

Whatever "machinery" is formulated as a theory of constructions, the participator idea implicit in the theory structure is necessary in order to understand.

In this paper we have proved that by starting from bit strings generated by *program universe* and labeled by the $2^{127} + 136$ strings provided by any representation of the four-level *combinatorial hierarchy* one gets an S-matrix theory with the usual C, P, T properties, CPT and crossing invariance, manifest covariance, unitarity and clustering. Arbitrary choice and non-locality provide the supraluminal correlations experimentally demonstrated in EPR experiments without allowing supraluminal transmission of information. As is true for any quantum mechanical theory, ours stands because of the outcome of Aspect's and similar experiments, and would have to fall if these are rejected. We claim to have arrived at an *objective* quantum mechanics with all the needed properties.

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