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WHERE WE ARE*

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ABSTRACT

The conceptual consequences, cosmology and physical predictions stemming from the *combinatorial hierarchy* and a *discrete physics* model based on McGoveran's *ordering operator calculus* are reviewed. We conclude that we have made a strong case for this approach to the foundations of physical science.

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1. INTRODUCTION

At ANPA 9[1], I was willing to admit that I believe we are engaged in trying to create a scientific revolution. Subsequent events have strengthened my conviction that this was not an idle statement, and rekindled some revolutionary ardor. Thanks to McGoveran's *ordering operator calculus*[2] we have not only been able to give a reasonably complete understanding of why a finite and discrete theory necessarily provides a common explanation for quantum mechanics and special relativity[3,4] but to make a start on meeting the three original tests of *general* relativity[5]. The clincher for me was McGoveran's calculation of the *second order* correction to the hierarchy exoskeleton (scale constant) value for electromagnetic interactions. This calculation[6,7] foreshadows a new era of quantitative predictive power for our theory, as I will discuss in my paper entitled *What Is To Be Done* at ANPA WEST 5[8]. The paper before you focuses on one task set for me by President Kilmister for ANPA 10, namely to provide an overview of what has *already* been accomplished. I discuss below progress which has been made in the conceptual foundations of our program, some of the cosmological implications, and the outline of our theory of elementary particle physics which is beginning to emerge. I conclude with "Homework problems" for ANPA 11.

2. CONCEPTUAL FOUNDATIONS

The conceptual foundations of our theory have been discussed in some detail by Gefwert[9] and McGoveran[2] in last year's proceedings. I emphasize that we follow the *modeling methodology* developed by McGoveran, which in the application at hand *starts* with the contemporary practice of physics as the problem to be modeled. In order to have a self-consistent formalism which can be related to this *epistemological framework*, it is necessary to develop a *representational framework*. As Bastin and Kilmister have emphasized, this framework must not use theory-laden language; we avoid this trap by insisting that the R-frame be strictly computable. To complete the modeling task we must establish rules of correspondence (a *procedural framework*) which connect the R-frame to the E-frame. In our application these will obviously include what is usually called "comparison with experiment", but will by no means be limited to this aspect of the problem. Many iterations of these steps in theory construction will have to be performed before we can decide that the theory is indeed successful, or will have to be modified or abandoned. Roughly speaking, this approach to physics is not very different in outline from the best contemporary practice; we have found it very useful to give more precision to this practice.

The place where we most obviously part company with contemporary practice is in the principles on which we base the construction of the R-frame, which in this application includes what McGoveran calls the *ordering operator calculus.* The five principles are strict finiteness, discreteness, finite computability, absolute non-uniqueness and strict constructability. We reject the continuum from the outset. We must state in advance how far we intend to count; if we find that we want to exceed this bound, all arguments must be re-examined. In the absence of further information, we must use equal prior probabilities for alternatives. We are necessarily context sensitive in our constructions and encounter indistinguishables in many of these contexts. This makes our theory richer than continuum theories. We must often consider the fact that many different "histories" could have led us to a particular point in a particular construction, and that in the absence of further information, we must assign equal weight to each of these. In return for this increased complexity some problems become much simpler for us. For those familiar with Kuhn's model for scientific revolutions, this should come as no surprise. Any new fundamental theory finds some problems easier to solve, and for other problems loses (sometimes for a long while) some of the explanatory power of the theory it is attempting to replace.

We now discuss several points where we believe we gain in explanatory power compared to conventional theories.

• 3+1 asymptotic space

In many conventional theories, the three dimensional structure of space and the sequential character of time are accepted as brute facts. Recently "string theories" give another argument. They accept both quantum mechanics and relativity, and start with a 26-dimensional structure whose uniqueness can be questioned. An argument in its favor is that, as the theory develops, this structure "compactifies" in such a way that only the usual 3+1 space-time is relevant at large distances compared to the elementary particle scale. For us, this 3+1 structure for events follows directly from McGoveran's Theorem, once our basic principles and rules of correspondence are understood. Assume dichotomous choice for any attribute we use to set up a metric and map onto D distinct sequences. We *synchronize* the sequential count by identifying a starting place in each sequence. Require that the labels which keep the sequences distinct cannot be used to distinguish the construction of one sequence from another (i.e. the construction is "homogeneous and isotropic"; labels specified only by discriminate independence are obvious candidates). Then McGoveran proves that the probability of being able to construct the n^{th} metric mark for all D sequences under these constraints is strictly bounded by $n^{-\frac{1}{2}(D-1)}$. Sum these probabilities up to some finite N and normalize. For $D = 2, 3$, there is a finite probability that the construction can continue to produce sequential homogeneous and isotropic metric marks in each dimension for any finite N, but for any larger number of dimensions this probability is strictly bounded by $1/N$; one can wait till hell freezes over for the next metric mark to occur in all $D \geq 4$ dimensions. Hence 3 homogeneous and isotropic dimensions must separate out once we count far enough (to 20 or so is enough for most practical purposes) using any universal ordering sequence that can be mapped onto the ordinal integers. We claim that this explanation gets to the heart of the matter for any theory such as physics that relies on finite counting.

• transport (exponentiation) operator

• combinatorial construction of π

One interesting development is that McGoveran has given, for finite N, the combinatorial definition of the exponential $e(N) = 1/N!$ as the ratio of all permutations to all complete permutations. This can be generalized to define a transport operator in terms of a finite "Taylor series" with a combinatorial definition of the coefficients. Since, in practice, any theory based on analytic functions has to expand them in finite Taylor series, and thus provide a combinatorial definition of the coefficients, we have explained to our satisfaction why physics is based on analytic functions and recovered for our theory the consequences of this. Another development is Mcgoveran's construction of finite coordinate patches with either square or radial symmetry. The ratio of perimeters gives one algorithm for computing $\pi(N)$ — in fact the Archimedean algorithm used in computer practice — and the ratio of the areas another. This reminds us that in our theory "π" is always, in principle, defined by a rational number depending on context and can be thought of as "empirical".

- limiting velocity
- supraluminal synchronization and correlation *without* supraluminal signaling

At a somewhat less fundamental level than the global "irreversibility of time" and the "3-dimensionality of space", all conventional theories take the existence of a limiting velocity as a "just so story". In contrast, we derive it from our fundamental principles. Attribute distance relative to some reference ensemble is defined as the number of computation steps which take the ensemble away from the reference ensemble minus the number toward - coincidence defined by local isomorphism *with respect to the attribute in question.* Therefore any attribute, reference ensemble and computational procedure define a "limiting velocity" or "computational band width" as the difference between these quantities divided by their sum (i.e. by the total number of steps or "computation time"). The Lorentz transformations follow in due course[2]. Further, since the transfer of causally effective ("physical") information requires the specification of *all* the attributes which go to specify a "physical object", the limiting velocity of physics has to be identified as the *minimum* of these limiting velocities. Hence we anticipate "supraluminal" correlation and synchronization without "supraluminal signalling", which in our view is the guts of the EPR situation[10].

- discrete events

Although our definition of "event" is very different from that used in second quantized field theory or S-matrix theory, we end up with our own discrete version of Feynman Diagrams, the CPT theorem, crossing and scattering theory. Whatever means we use to generate these diagrams and to obtain the combinatorial hierarchy, our theory as technically articulated depends on *bit strings* (ordered strings of zero's and one's or any two distinct symbols) which combine by *discrimination* (OREX, exclusive or,...): when the strings are the same $(aa)_n = (0)_n$ where the *null string* $(0)_n$ consists of n zeros; when they are discriminately independent $(ab)_n = (c)_n$, all non-null and c is distinct from a and from b. A 4-event is then defined by $(abcd)_n = (0)_n$, and by our rules of correspondence (the "counter paradigm") can be associated with the chain of happenings in the laboratory which lead to the "firing of a counter" or some conceptual equivalent. Our generation procedure leads to concatenated strings $(a)_{L+n} = (L_a)_L \| (A^a_x)_n$ where the first part is called the *label* and the second the *content*. The labels are of fixed length L and each is one of the $3 + 7 + 127 + 2^{127} - 1$ members of some representation of the 4-level *combinatorial hierarchy*[11,12] . Once the label strings are constructed, their *closure* under discrimination allows us to assign *invariant* attributes and parameters to them. The content strings can be any one of the possible 2^n strings of length n and grow in both length and number per label as the investigation proceeds.

- discrete Lorentz transformations (for event-based coordinates)

To go from this definition of event to event-based coordinates, we consider an event involving some label, and after the content strings have grown by some increment n, a second event involving the same label. Taking as our attribute the number of 1's in this incremental content string k_a and as our reference ensemble any string with $2k = n$, the attribute distance between these two events is $k_a - (n - k_a) = 2k_a - n$. Our rule of correspondence is to assign the invariant step length $\lambda_a = h/m_a c$ to the label a, and the time per step $\Delta t = \lambda_a / c$ where c is the limiting velocity. Then taking the first event as the origin, the distance between the two events $x = (2k_a - n)\lambda_a$ and the time $t = n\Delta t$ define the interval $s^2 = c^2t^2 - x^2 = 4k_a(n - k_a)\lambda_a^2 = (1 - \beta_a^2)n^2\lambda_a^2$ and the average velocity between the two events as $\beta_a c = (\frac{2k_a}{n} - 1)c$. Clearly the interval is invariant under the transformation $k' = \rho k, (n' - k') = \rho^{-1}(n - k)$ and the Lorentz transformations with $\gamma = \frac{1}{2}(\rho + \rho^{-1})$ in 1+1 space time or momentum-energy space follow immediately.

- relativistic Bohr-Sommerfeld quantization
- non-commutativity between position and velocity (for event-based coordinates)

Conventional theories have to take both the limiting signal velocity and the quantization of action as "given" because they have no way of deriving either concept. Granted this much, their second quantized free space theory can be formulated, but trouble starts once they try to embed the discrete, non-local events implied by quantum theory into the continuous space-time of special relativity. Because of the uncertainty principle this necessarily assigns an infinite amount of energy at each space-time point! Fifty years of struggling with this problem has produced, thanks to a generous input of practical information about elementary particles, a "non-Abelian gauge theory" which is finite, but which gives the universe at least 10^{120} times too much mass-energy; we return to this point when we discuss cosmology in the next section. For us, the reconciliation between quantum mechanics and relativity occurs at an appropriately fundamental level without invoking all this complicated technical apparatus.

We have seen above that our discrete principles require us to take discrete steps of finite length executed at the limiting velocity, achieving lower velocities, on the average, when some steps are toward and some away from the reference position. Because velocity can have a common significance in either space-time or energy-momentum space, we can use the invariance of the labels as the investigation proceeds either to assign an invariant step length h/mc or an invariant mass to each of the $2^{127} + 136$ distinct labels. Note that our definition of velocity, $\beta c = [\frac{2k}{n} - 1]c$, is invariant under the transformation $k' = Tk, n' = Tn$; for $T \geq 1$, T counts the number of positions "along the line" where events can (but need not) occur, or in the language of wave theory, where interference can take place. We could introduce the constant of action h by specifying the invariant mass and quantizing this periodic possibility using $E = h/T = h\nu$ rather than by taking the invariant length to be $\lambda = h/mc$. Clearly the two quantizations are equivalent and give us the *relativistic* deBroglie relations.

It is important to realize that this relativistic periodicity is defined even for a particle "at rest", i.e., with $n = 2k$. Since each step is executed at the limiting velocity, each step starting from rest changes the momentum by $\pm mc$, and we must take at least two steps in position and two steps in velocity in order to return to the rest position. This *zitterbewegung* associated with the rest energy mc^2 implies that even a "free particle" executes a periodic motion in phase space which encloses an area nh with n integral. Our theory automatically extends Bohr-Sommerfeld quantization to relativistic free particles. This fact underlies the success of our calculation of both the Sommerfeld formula for the fine structure of hydrogen and our correction to the lowest order hierarchy result $\hbar c/e^2 = 137$ discussed below. Further, since the changes in position and in velocity occur sequentially around this circuit, the determination of either becomes order-dependent and non-commutative. As is discussed in detail in Ref. 2, this non-commutativity between position and velocity is a necessary feature of any finite and discrete theory.

- conservation laws for Yukawa vertices and 4- events
- crossing symmetry

There was considerable discussion at ANPA 10 as to whether we in fact had proved the equivalent of vector conservation laws in 3-space for our "Yukawa vertices" and 4-events. This problem is only partly met in Ref. 4. Further analysis shows that we have precisely the conservation laws needed for 4-event crossing if one realizes that on mass shell 3-momentum conservation in a 4-event leaves only 9 degrees of freedom, and that the internal (in general off mass shell) velocity for the system connecting two incoming to two outgoing masses is defined by discrimination, (i.e. by the common string any pairwise decomposition of a 4-event that the definition allows). Consider the $a + b \rightarrow c + d$ channel $(ab)_n = (cd)_n$ and note that $|k_a - k_b| \leq k_{ab} \leq k_a + k_b$ and that $\beta_{ab} = \frac{2k_{ab}}{n} - 1 = \beta_{cd}$., The four external velocities and the four external masses taken together with *this* connecting velocity precisely specify all the momenta and angles for the conventional problem. Then the constraints implied by $(abcd) = (0)$ connect the $(ab) = (cd)$, $(ac) = (bd)$ and the $(ad) = (bc)$ channels in precisely the way crossing requires in the conventional theory. This will be spelled out in more detail some time during the coming year.

Of course *any* fundamental theory of MLT (i.e. mass-length-time) physics must compute everything else as physically dimensionless ratios once any three independent dimensional constants are fixed. Conventional theories take c and $\hbar$, and the structures implied by them for granted; we showed above that they are, for us, structural consequences of our basic principles. We share with other physicists the scale-invariant *laboratory* methods of relating c and $\hbar$ to arbitrary standards of mass, length, and time. Granting this much structure to conventional theories, conventional physicists still need some mass or dimensional coupling constant that has to be taken from experiment. Once again the existence of this unique constant — let alone a means of computing it within the theory — is not available to the theorist; this is not an obvious structural requirement of conventional practice. We not only obtain a first order estimate for the dimensionless $\hbar c/e^2 \simeq 137$, which would allow us to take as our third dimensional constant the quantized electric charge of elementary particles, but also the remarkable connection $\hbar c/Gm_p^2 = (M_{Planck}/m_p)^2 \simeq 2^{127} + 136$. This connection between the elementary particle, electromagnetic and gravitational scales naturally leads us to consider next the cosmological implications of the theory.

3. COSMOLOGICAL EXOSKELETON

- the equivalence principle
- electromagnetic and gravitational unification

Conventional cosmologies usually start from the general theory of relativity, which in turn starts from the postulate of the equivalence between gravitational and inertial mass and then explains gravitational effects as due to the space-time curvature introduced by the presence of mass-energy. Source-free electromagnetic fields of sufficient energy to trap themselves as standing waves held together by their own gravitational fields (geons) unify the two "classical" field theories in a conceptually satisfactory way, as was proved by Wheeler long ago. His theory depends only on G and c; it is *scale invariant.* Once a third dimensional constant (eg e^2 or h or any elementary particle mass) is introduced, the short distance behavior of the theory becomes ambiguous. The difficulty, of course, arises once again because of the continuum assumption that drags the theorist down to the natural cutoff length $\hbar/M_{Planck}c = [G\hbar/c^3]^{\frac{1}{2}}$ and below. The related problems of "quantum gravity" are a major field of contemporary theoretical physics research.

Once again the problem is much simpler for us. Because

$$\hbar c/Gm_p^2 = (M_{Planck}/m_p)^2 = 1.6937(10) \times 10^{38}$$

the hierarchy result,

$$2^{127} + 136 = 1.70147... \times 10^{38}$$

thanks to my interpretation[13] of Dyson's argument[14] implies that this is a first order calculation of the same number, we can take as our unit of mass either the proton mass or the Planck mass. Since ours is a *fundamental* theory, all masses must be computed in ratios to our unit of mass. We have no place in the theory for two different kinds of mass. Thus for us the "equivalence principle" is a deductive consequence and not a postulate. There is no need for us to "geometricize" gravity at this level of the discussion. Further, since the same hierarchy construction gives us both the electromagnetic and the gravitational couplings, the theory is "born unified", and the gravitational coupling affects everything, including electromagnetic quanta. We have here the starting point for a quantum theory of geons, a problem whose solution eluded Wheeler.

- the three traditional tests of general relativity

As will become clearer when we discuss the Bohr atom and the Sommerfeld formula in the next chapter, so far as non-relativistic "orbits" go, the Coulomb attraction and Newtonian gravitation can be described in the same way except for the scaling ratio we have already computed — i.e. $e^2/Gm_p^2 = [2^{127} + 136]/137$. Consequently, if we compare the energy of a photon emitted near the surface of the sun with the energy it delivers when absorbed near the orbit of the earth, we will find that it is "red shifted" by the observed amount, thanks to our relativistic kinematics. For a photon emitted by a star and subsequently traveling near the sun on its way to us, this "Newtonian" interaction produces only half the observed deflection of starlight. However, our theory gives us spin 1 traveling photons, and we believe (though have yet to demonstrate in detail) that it gives spin 2 gravitons as well as the Newtonian term. [If this assumption fails, our theory is in serious trouble.] For any spin 1 photon, only one of the two helicity states can interact with the spin 2 graviton, because it can do so only by flipping the spin of the photon one way; this provides us with the needed factor of two. For gravitons emitted and absorbed by macroscopic objects, the Newtonian term gives only one-sixth the observed precession of the perihelion of Mercury. In this case, all five possible orientations of the spin 2 gravitons with respect to the plane of the macroscopic orbit, and not just the two helicity states, are relevant, giving us the needed factor of six. This argument is discussed a little more carefully in Reference 5, and provides an approach to meeting the traditional tests of general relativity within our framework. We do not as yet know how to tackle the effects of strong gravitational fields in bulk matter (eg macroscopic "black holes") from first principles.

- event horizon

• zero-velocity frame for the cosmic background radiation

General relativistic cosmologies coupled with the recessional velocity interpretation of the Hubble red shift necessarily drag the theorist down into extreme densities at early times. Hopefully they also connect the cosmological problems of origin to elementary particle physics in a very exciting way. But once swallowed, the theorist finds himself in a cloud coo-coo land from which he can extract himself only by making heroic efforts. Our problems are again much simpler because we cannot even begin to talk about space and time— the content strings — until we have generated the hierarchy labels. Although the details will depend on just what generation scheme we adopt, it is clear that in order to start talking about particles, space and time, we will need to have on hand at least the 139 discriminately independent basis strings of fixed length from which the hierarchy can be constructed in due course. Then we can start forming the content label ensembles which describe velocities, and the 4-events which allow us to specify the conserved quantities and to talk about the baryon number and lepton number of the universe. Whenever and however the appropriate label string length is fixed, the content string length continues to grow. This content string length specifies the "event horizon" of an expanding (in fact, as Wheeler once noted, an "uncrunchable") universe. Once the strings have appreciable length the average velocity is zero because the most probable number of 1's is half the string length, This fact defines the unique "zero velocity frame" for the background radiation and everything else. Of course this is no more in conflict with "special relativity" than the brute fact of the experimental discovery of this frame is for conventional cosmologies.

• mass of the universe

We assume that our cosmology stems from a generation scheme of the *program universe*[15] type in which two arbitrarily selected strings either produce a non-null string by discrimination or increment all extant strings by a single bit arbitrarily chosen for each string. Once we have generated 139 discriminately independent (basis) strings and fixed the label length L, we will need at least 2^{127} discriminations involving about $[2^{127}]^2$ strings to close the hierarchy labels and fix quantum number conservation in the terms discussed in the next chapter — i.e. with the usual particulate interpretation. We conclude that there must be at least $[2^{127}]^2$ particles around when we first can start to talk about baryon number conservation in "space-time" in a way that relates (linearly ?) with the here and now universe in which we practice physics. We can now make a choice — on cosmological grounds — of our unit of mass. If this is the proton mass, the mass of the universe will be around $2^{254}m_p = 4.84 \times 10^{52} gm$, which as we will see shortly is about right according to standard interpretations of current observations. If we were to take the Planck mass as the unit, as has been suggested occasionally, we would be out by a factor of 10^{19}. So we settle on m_p, or something close to it, as the basic mass to which we will relate all others. The conventional wisdom is in much worse shape here than we are. Most of their model universes are buried under a pile of (BLEEP) that weighs 10^{125} times[16,17] too much for them to dig their way out from under it - except by the observation that we nevertheless exist, and that human ingenuity should be able to find an explanation. Current efforts to meet the problem usually involve an inflationary scenario which necessarily ends up with the critical density (i.e. just the right amount of matter to close the universe) and may have advantages in smoothing out early fluctuations, but we think it simpler not to get into the problem in the first place.

- fireball time
- critical density

Now that we have identified c, $\hbar$ and our unit of mass, the unit of time is fixed as $\hbar/m_pc^2$. Although it takes a minimum of 2^{127} discriminations to get all the labels, each label is picked arbitrarily; the sample space contains $[2^{127}]^2$ pairs. We conclude that it will take $[2^{127}]^2\hbar/m_pc^2 = 3.5$ million years. before we can talk about "space", "time" and "particles" in anything lake an ordinary sense. Clearly the universe is still "optically thick" up to this time. Since the initial content strings are very short, they will have velocities which are substantial fractions of c, making the initial universe very hot. This heat will be further enhanced by the decays of higher generations of quarks and leptons once the receding event horizon provides them world enough and time to decay into. For our density (see below), 3.5 million years will also be about the right time for the transition from an optically thick to an optically thin universe to occur. This is our estimate of "fireball time" — i.e the time when the radiation breaks away from the matter.

Of course the "time" calculated above involves the usual fiction that we can reliably extrapolate the universal expansion now observed using the laws of physics established here and now back into the hot plasma that is implied before fireball time and indeed linearly all the way down to a point singularity. Clearly both space and time loose their usual significance long before the singularity is reached. In our model we must construct some substantial fraction of the labels before they have even a modest connection with their usual meanings. From fireball time on, when the universal expansion is matter dominated; the linear extrapolation (or retrodiction) is plausible. Our "fireball time" is consistent with a universe that is 1.5×10^{10} years old and a Hubble constant of 50 $km/[s \cdot Mparsec]$ if we extrapolate backward from the currently observed $2.7^o K$ background radiation. These assumptions fix the current radius of the event horizon as 5.92 $\times 10^{26}$ cm; with our mass of $[2^{127}]^2 m_p = 4.84 \times 10^{52}$ gm our model has a density of known particle types relative to the critical density ρ_c (i.e. the density needed to just "close" the universe) of $\Omega = \rho/\rho_c = 0.01175$. Here we have taken our figures from Faber[18] and hence under our assumptions take the critical density to be 4.75 $\times 10^{-30}$ gm. His limits for this number for visible matter are $0.005 \leq \Omega_{Vis} \leq 0.02$ and for baryonic matter are $0.04 \leq \Omega_{Bar} \leq 0.14$. The higher limits for baryonic matter depend on detailed arguments about the cosmo- and nucleo-genesis of light elements ("deuteronomy"). Until we have our own calculation for these processes, which will differ in significant ways from the standard ones, we take the observational ("visible matter") number as the one to compare with our model, and are pleased by the agreement achieved. We cannot really calculate the 10^9 photons per baryon implied by our numbers, and have taken it from observation, which is standard practice.

- dark matter

The prejudice of most cosmologists is that the universe should be closed, or "just closed". In fact the current fashion, as noted above, is to use an inflationary scenario which predicts $\Omega = 1$. I find an open universe much more satisfactory, particularly after reading Dyson's scientific eschatological analysis[19]. The observational "deficit" from the conventional perspective is now to be made up by "dark matter". Here they have a good observational case in that ten times as much of the mass of galaxies, as measured by Newtonian gravitation and the Doppler shift, is "dark" rather than electromagnetically visible. How much more there is depends, once again, on details of the cosmological model rather than on observation.

Here our theory makes a new prediction. Visible matter can only be understood by us in terms of the 137 labels for the first three levels of the hierarchy. But there are 3+7=10 labels that cannot be interpreted prior to the formation of the "background" of the 127 labels which make up level 3. Whatever they are, they must be electrically neutral and will occur, statistically, 12.7 times more frequently than the level 3 labels. They could form electromagnetically inert structures at any scale compatible with our finite scheme (quantum geons?). So our estimate of the ratio of the amount of "dark matter" left over from the "big bang" to the visible matter is 12.7; a better estimate will depend on what version of the early stages of *program universe* we use. To understand in more detail how we can expect to get dark matter out of our theory we must first understand how we get ordinary matter, which is discussed in the next chapter.

4. ELEMENTARY PARTICLE PHYSICS

• quantum numbers of the standard model for quarks and leptons

Our general derivation of conservation laws and crossing for 4-events applies to the labels and (because the labels close) can be used to define additive conserved quantum numbers. This is discussed in Reference 4; we omit several technical details here. Although the labels are constructed from the "bottom up" by generating the combinatorial hierarchy, the physical interpretation is most easily explained from the "top down".

- gravitation: $\hbar c/Gm_p^2 = 2^{127} + 136 = 1.70147... \times 10^{38}$ $[1.6937(10) \times 10^{38}]$

Level 4. Our method of construction[15] necessarily assigns to level 4 all labels which couple to the lower levels. The universal label is simply the anti-null string $(1)_L$ containing L ones, which obviously couples to everything and also takes a particle label into an antiparticle label. Clearly this can be identified with Newtonian gravitation, and indeed has the right coupling constant, since it occurs with probability $1/[2^{127} + 136] \simeq Gm_p^2/\hbar c$. For weak gravitational fields this will carry either a null or an antinull content string and hence define the gravitational "light cone". The next simplest strings will be the spin 2 gravitons, which also carry one of these two content strings and will be constructed from a lepton-antilepton (levels 1 and 2) and a quark-antiquark (level 3) pair, insuring that they also couple to everything.

- weak-electromagnetic unification:

$G_F m_p^2 = 1/(256^2\sqrt{2}) = 1.07896 \times 10^{-5}$ $[1.02684(2) \times 10^{-5}]$

$sin^2\theta_{Weak} = 0.25$ $[0.0229(4)]$

- quark-lepton generations

The charged weak bosons $W^{\pm}$ couple an electrically neutral neutrino to a charged lepton (electron or quark) in the same way for each generation. Using 16 concatenated strings of length 16 to represent 16 generations, they will occur with probability 256^{-2}. Because of a conventional difference between the way the Fermi and the Yukawa couplings are written, this corresponds to a Fermi coupling constant $G_F m_p^2 = 1/[256^2\sqrt{2}]$. For the neutral weak boson (Z_0) to also be pseudoscalar — the obvious first approximation — we need the weak angle (conventionally defined) to be $sin^2\theta_{Weak} = 0.25$ compared to the empirical value[20] of 0.229 ± 0.004. We have yet to carry out the mass ratio calculations for these particles. Electrons couple to the coulomb and spin 1 massless vector quanta (i.e. photons) within level 2 and to two flavors of quarks with 1/3 or 2/3 the same probability within level 3. Since the electromagnetic interaction crosses the first three levels, and the pattern repeats for higher generations, the lowest order calculation of the coupling is $e^2/\hbar c = 1/137$.

- color confinement — quark and gluon masses not directly observable
- $m_{u,d}(0) = \frac{1}{3}m_p$
- the generation structure

Level 3 contains two flavors of fermion-antifermion pairs (16 states) with three colors in an octet (8 states) making up the 128 -1 =127 distinct labels required for this level. The 1 is subtracted, as usual, because the null string is not allowed as a label. Since McGoveran's Theorem grants us only three asymptotic degrees of freedom, and hence (for the quantum numbers) only three exact (to order $1/[2^{127} + 136]$) conservation laws, we take these to be charge, baryon number and lepton number in order to correspond to experience. Then there is no way that colored quarks or their associated colored gluons can appear asymptotically. In other words "color confinement" is a necessary consequence of our theory. In the first generation, we can use three quarks to form fermion color singlets with no charge or one unit of charge (neutron and proton). Neglecting the internal (unexamined) energy, the quarks in these systems will have one third of a nucleon's mass. We anticipate that when neutrons and protons are probed at high energy the *effective* mass of the quarks and gluons will fall off (asymptotic freedom), but have not as yet proved that this happens. Mesons are quark-antiquark pairs in appropriate colorless color-anticolor combinations;, the usual connection to low energy nuclear physics is maintained.

Level 2 consists of electrons, positrons, massless spin 1 quanta (photons) and the coulomb interaction. *Level 1* contains the two chiral neutrinos responsible for parity non-conservation, but whether the associated quantum is a graviton or the Z_0 can only be determined by looking back up to level 4. As already noted, this pattern can repeat 16 times to form 16 generations. Necessarily the coupling from lower to higher generations will diminish dramatically with generation number because of the combinatorial explosion; we are not yet in a position to make this statement quantitative by calculating the Kobiyashi-Maskawa mixing angles.

• dark matter again

Now that we understand the coupling scheme in more detail, we can see that when the construction starts we will get labels corresponding to the first two generations 127/10 times as often as we get the third generation labels which first allow us to talk about electromagnetism and visible matter. Eventually some of these more complex labels will settle down into the pattern explained above, but initially will be coupled to each other only by pre-gravitation. This fact is our reason for believing that with more work we will have a model for "quantum geons" composed of neutrinos, gamma rays and gravitons with 10 identifiable quantum states, as we mentioned above when discussing cosmology. Whether this dark matter will nucleate correctly to form the dark matter of the galaxies is still conjectural.

• the hydrogen atom

A hydrogen atom consists of an electron and a proton whose mass ratio is discussed below. Since our first order scheme requires that only 1 in 137 of the events which bind this composite structure will be a coulomb event, the other interpretations of the labels average out in the first stage of the analysis; in other words

$$137 N_B \ steps = 1 \ coulomb \ event$$

This means that we now have two frequencies (in dimensional units of $\mu c^2/h$), the *zitterbewegung* frequency corresponding to the system mass μ, which we take to be unity, and the coulomb frequency $1/137N_B$. Since these two motions are incoherent, the frequencies must be added in quadrature subject to the constraint on the energy E defining a bound state that in the rest system $E/\mu c^2 < 1$. One way to express this constraint is

$$(E/\mu c^2)^2[1 + (1/137N_B)^2] = 1$$

In the language of the ordering operator calculus, this is simply the normalization of the metric corresponding to the energy attribute under the appropriate constraint. If we take $e^2/\hbar c = 1/137$, this is just the relativistic Bohr formula[21].

• the Sommerfeld formula

In either the non-relativistic Bohr theory or the non-relativistic Schroedinger equation, the coulomb problem suffers from a degeneracy between the principle quantum number N_B and the orbital angular momentum quantum number ℓ, because the energy depends only on the principle quantum number, or, in the correspondence limit, on the semi-major axis of the ellipse. Thinking semi-classically, Bohr[21] and Sommerfeld saw that the relativistic mass increase, which is most important at perihelion in elliptical orbits, would break this degeneracy, and Sommerfeld[22] computed the effect. Dirac[23] arrived at the same formula in what appears to be a very different way, but one which also depends on lifting the degeneracy between two integers. For both Sommerfeld and Dirac the problem was, in a sense, easier than for us because in conventional theories irrational, transcendental, "empirical", ... numbers live in a different world than the finite integers. Their methodology allows these non-constructive entities to enter the argument at appropriate points. We must face a harder problem in our theory.

Let j be an integer, and let successive values of s differ by integers so that $s = n + s_0$. Although s_0 is rational, it lifts the degeneracy by being non-integral. If j and s_0 differed *only* by a rational fraction rescaling would restore the degeneracy. Hence the 137 coulomb rescaling from the combinatorial hierarchy exoskeleton, or any other single integral rescaling, is not enough to meet the problem posed. If we combine the two independent integer (except for s_0) counts by starting them off as close as we can while maintaining the distinction (i.e. "synchronize" the counting), we can require that s_0 be the value closest to j that s can have. This can happen in two distinct ways. There is no way in the problem posed that we can directly observe the "synchronization" of the two periods, and both possibilities correspond to "coulomb events". We can either assume that the synchronization corresponds to $137j\frac{steps}{(coulomb\ event)} + 137s_0^+\frac{steps}{(coulomb\ event)} = 1 + \epsilon$ or to $137j\frac{steps}{(coulomb\ event)} - 137s_0^-\frac{steps}{(coulomb\ event)} = 1 - \epsilon$ where ϵ is some rational fraction less than unity.

Here we must use care because these two equations have different meanings and cannot simply be interpreted as if they represented numerical quantities which can be combined by linear operations. As we saw in our derivation of the relativistic Bohr formula, independent frequencies must be combined in quadrature. We can form the specific product defining the squares: $137^2 j^2 - 137^2 s_0^2 = 1 - \epsilon^2$; ϵ still must be computed. Note that the two factors of this equation are the conditions on j and s_0 stated above. With j fixed, the two values of s_0 implied by this equation were called $s_0^{\pm}$ above. Since j is to be the norm to which we refer, we form $j^2 - s_0^2 = (1-\epsilon^2)/137^2 = a^2$. Taking $s = n + s_0$ as the appropriate number to define internal frequency for the bound state, we can follow our discussion above for the single frequency case and conclude that

$$(E/\mu c^2)^2[1 + a^2/(n + \sqrt{j^2 - a^2})^2] = 1$$

This is precisely the Sommerfeld formula, provided we can interpret a^2 as α^2 (to order a^3 or α^3) and know how to take the square root in our discrete theory.

- the fine structure constant: $\frac{1}{\alpha} = \frac{137}{1 - \frac{1}{30 \times 127}} = 137.0359674...[137.035963(15)]$

In order to understand how we can have two independent rational frequencies in our theory of this problem, we have to go back to where the 137 came from. In the absence of other information, the 3 + 7 + 127 labels have to be generated for each of the two labeled strings which are coupled by the two coulomb events that (minimally) allow a bound state to be specified. But, if the end result is to be distinct, the way this is done the first time must be distinct from the way it happens the second time. For both events to be coulomb, the second time through the first two levels must already have closed, so only 1 in 127 events would correspond to an indistinguishable repetition of the first process. Hence the population from which a coulomb bound state event is selected is reduced by 1 in 127 compared to statistical independence; this is standard statistics for sampling without replacement. But for two spin 1/2 particles (electron and proton) only 1 in 16 possibilities out of the spin, particle-antiparticle, dichotomies will also coincide; the null case cannot occur in our scheme, leaving only 1 in 15 $\times$ 127 cases to be excluded. We conclude that the expectation of the "second" event being degenerate with the "first" event is just $1/(15 \times 127)$, which defines $2\epsilon = \frac{1}{15\times 127}$ as the interval around unity by which $137^2 s_0^2$ can differ from $137^2 j^2$. In the physical situation we are only interested in the portion that occurs within the period for j, namely $1 - \epsilon$. Therefore the statistical estimate for the fraction of the number of the steps that are neither part of j or s_0 is $\epsilon = \frac{1}{2} \cdot \frac{1}{127\times 15}$

This two factor analysis of the way ϵ relates to the normalization equation $j^2 - s_0^2 = a^2$ raises another subtle point. When experimentalists use the Sommerfeld formula and the fine structure spectrum of hydrogen to evaluate α, they fit their results to α^2 and then take the square root. In order for this to correspond to the calculation we have made, we must take $a^2 = (1-\epsilon)^2/137^2$, and we expect them to find that $\frac{\mathbf{1}}{\mathbf{a}} = \frac{\mathbf{137}}{\mathbf{1}-\frac{\mathbf{1}}{\mathbf{30\times 127}}} = \mathbf{137.0359674...}$ in comparison to the accepted empirical value[24] 137.035963(15).

Looking ahead, it is important to realize that the Sommerfeld formula in fact only holds for the fixed center problem, and cannot be corrected for the case of two finite masses by using the non-relativistic system mass $\mu = \frac{m_1 m_2}{m_1+m_2}$. The formula to order e^4 is given :[25–27] by:

$$S_n = m_1^2 + m_2^2 + \frac{2m_1 m_2}{[1 + Z^2\alpha^2/(n - \epsilon_j)^2]^{\frac{1}{2}}}$$

where

$$\epsilon_j = j + \frac{1}{2} - \sqrt{(j + \frac{1}{2})^2 - Z^2\alpha^2}$$

and j is the total angular momentum for the Dirac case, or the orbital angular momentum (ℓ) for the spinless (Klein-Gordon) case. This is to be compared with the invariant mass for two free particles with velocities β_1, β_2, which is

$$M^2 = m_1^2 + m_2^2 + 2m_1\gamma_1 m_2\gamma_2(1 - \beta_1\beta_2 cos\ \theta_{12})$$

where $\gamma_i = [1 - \beta_i^2]^{-\frac{1}{2}}$ and θ_{12} is the angle between the two velocities. Note that the *zitterbewegung* of the two masses adds in quadrature, which we argue it should on general grounds. Hopefully by the time of ANPA 11, or with some luck by the time of ANPA WEST 5, someone will see how to extend David McGoveran's calculation to two finite masses; this critical step must be taken before we can go on to muonium and positronium.

- $m_p/m_e = \frac{137\pi}{\frac{3}{14}\left(1+\frac{2}{7}+\frac{4}{49}\right)\frac{4}{5}} = 1836.151497...$ [1836.152701(100)]

The m_p/m_e formula is due to Parker-Rhodes[28] Our theory differs from his. In the past we could only provide heuristic justification for the calculation. Now that we have a fully developed relativistic quantum mechanics, with discrete 3-momentum conservation, these past arguments become rigorous when we view the calculation as a calculation of the mass in the electron propagator — for us, a finite "self-energy". One puzzle was the extreme accuracy of the result, using 137 rather than the empirical value for $1/\alpha$. But now that we have found that the "empirical value" comes about in systems which lack spherical symmetry, or in combinatorial terms have two independent frequencies, and recognize that in the m_p/m_e calculation there is no way to define a second frequency, we have a rigorous justification for the formula as it stands. Numerically, we predict $m_p/m_e = 1836.151497...$ as compared with[24]: (old) 1836.15152(70) and (new) 1836.152701(100). We see that the proposed revision in the fundamental constants has moved the empirical value outside of our prediction by a presumably significant amount. For the m_p/m_e calculation the correction due to non-electromagnetic interactions could be large enough to affect our results.

- $m_\pi \leq 274 m_e$: $[m_{\pi^\pm} = 273.13 m_e,\ m_{\pi^0} = 264.10 m_e]$

The estimate of the pion mass was made long ago.[29] The model is due to our interpretation of Dyson's argument[14] that the maximum number of charged particle pairs which can be *counted* within their own Compton wavelength using electromagnetic interactions is 137. Taking these to be electron-positron pairs, we get the result. The argument in the past rested on the use of the Coulomb "potential". Now that we have a combinatorial calculation of the Bohr atom, we no longer need this extraneous element. If one looks at the *content* strings minimally needed to describe the possible states of the bound system, the saturation at 137 pairs emerges. As we can see from the Bohr atom calculation (eg by considering one electron or positron interacting with the average charge of the rest of the system), the first approximation for the binding energy is non-relativistic in that it neglects v^2/c^2 effects. Consequently the simplest estimate for the system mass, interpreted as the neutral pion mass, is just the sum of the masses, or 274 m_e, in agreement with experiment to better than ten electron masses. It will be interesting to calculate the α relativistic corrections (including the virtual electron-positron annihilation) and the neutral pion lifetime. Adding an electron-antineutrino pair to get the π^-, or a positron-neutrino pair to get the π^+, will be a good problem for sorting out our understanding of weak-electromagnetic unification.

5. CONCLUSIONS AND A LOOK FORWARD

By now the reader could grant that we have made a case for discrete physics as a fundamental theory. We have been led to many conceptual and numerical results that can only be obtained with difficulty, or not at all, by more conventional approaches. We believe the program will prove to be useful even if it ultimately fails. So far we have run into no insuperable barriers — frankly somewhat to my surprise. We have nailed down the quantum numbers in agreement with the standard model, and have computed reasonable values for the basic masses and coupling constants. Thanks to the high degree of overdetermination of elementary particle physics due to crossing and unitarity — Chew's bootstrap — we can expect to do about as well as conventional strong interaction theories. This means that when a difficulty *does* arise, it will suggest an area of phenomena that will deserve detailed experimental and theoretical examination.

Homework for ANPA 11

1.In the paper for ANPA 10, David McGoveran gave an argument for the $2 \times 15 = 30$ factor in the fine structure constant calculation as coming from $\binom{6}{2} + \binom{6}{4} = 30$ rather than the way it is computed here, using the states of two spin

1/2 particles. He is convinced that the fundamental combinatorial argument can be worked out without referring to spin. Of course the two arguments could turn out to be equivalent, or — in an interesting and perhaps testable sense — the fine structure "constant" will have different corrections for fermion-fermion, fermion-boson and boson-boson systems. A casual look at the relevant data does not rule this out. The reconciliation between the two points of view could lie in the multiple ways a fermion-antifermion pair can "define" a boson, and will deserve some careful work.

2.My revised abstract for the Conference at Imperial College on *Physical Interpretations of Relativity Theory*, (Ref.5) reads: "Starting from our discrete and finite version of relativistic quantum mechanics, we show that the first order estimates of $\hbar c/e^2 = 137$ and $\hbar c/Gm_p^2 = 2^{127} + 136 \simeq 1.7 \times 10^{38}$ derived from the *combinatorial hierarchy* allow us to solve the Rutherford scattering and hydrogen atom problems, and the corresponding gravitational problems as problems in probability. The three classical predictions of *general* relativity — red shift, bending of light, and precession of the perihelion of Mercury — follow when we include (as our theory requires) spin 1 propagating photons and spin 2 propagating gravitons. We predict that a *macroscopic* electromagnetic orbit would have 4 times the Sommerfeld precession for basically the same reason that Mercury has six times the Sommerfeld precession." Supply your own arguments for these conclusions.

3. Using your treatment of Rutherford scattering in problem 2, define the four quantum numbers $(m; \beta, \beta_{||}, J_z)$ with J_z the angular momentum component in the $\beta_{||}$ "direction" using labeled bit strings. Relate these to the basis states in the Pauli-Brodsky discretized version of second quantized field theory.

4. Calculate the fine structure spectrum of positronium and the first order line width correction due to singlet two-photon decay.

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Appendix*

ON TO QED

The time has come to make a frontal assault on the best protected fortress of the physics establishment — quantum electrodynamics (QED). In 1974 my advice[30], was that

"We should learn from our comrades in Southeast Asia that we must 'know our enemy' and attack where he is weak, not where he is strong. The strongest point in the defense of local field theory [my then current and continuing enemy, among others] is obviously QED [Quantum Electrodynamics], so we should leave this [attack] to the last and try to outflank it by finding weaker points."

By 1989 we are in a much more advantageous strategic and tactical situation.

I tabulate below the major victories already achieved[31,32] — none of which can be reached by standard methods. Conventional theories take as brute facts the general structural results which we have *established.* Our gravitational theory and cosmology are in accord with observation, and we find both more plausible than the conventional pictures. The way we view elementary particle structure has a simpler and more self-coherent origin than the received wisdom allows. All of our quantitative results are for numbers that standard theories have to take from experiment, and often do not allow to be calculated. This solid body of firm conclusions gives us a very strong strategic position. What is lacking is some decisive calculation that goes *beyond* what conventional theory has achieved in a region where it assumes *novel* theoretical or experimental predictions are possible.

The results now in hand open up a number of possible exciting physical applications of and improvements in our theory. I will discuss several of these in my paper[33] for ANPA WEST 5. Among these, the breakthrough achieved by McGoveran last year in calculating the fine structure constant[34] α offers a unique tactical opportunity for us to make calculations in quantum electrodynamics that are outside the grasp of conventional physics.

The fine structure constant $\alpha = e^2/\hbar c \simeq 1/137$ encapsulates much of nineteenth and twentieth century physics and chemistry. The symbol e^2 represents the laws of electrochemistry and chemical valence, as discovered by Faraday, and the square of the electric charge on the particulate electron as discovered by J.J.Thompson. The limiting velocity c (the velocity of light) refers back to Maxwell

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and Einstein. Similarly Planck's constant $h = 2\pi\hbar$ was the start of quantum mechanics. In 1966 Amson, Bastin, Kilmister and Parker-Rhodes computed the first approximation $1/\alpha = 137$. Taken together with the 1978 Parker-Rhodes calculation of the proton-electron mass ratio this now opens up most of the physics of here and now to attack by our theory. Discrete and combinatorial physics (our theory) is ahead of conventional methods because establishment physicists have to take "α" from experiment; the highest ambition of particle theorists is to calculate both the weak (β- decay) and strong (quark) interactions and the particle mass ratios using only this number α.

Bohr showed that the electron mass m_e taken together with c, h and α are enough to explain the visible and ultraviolet light (line spectrum) emitted and absorbed by hydrogen. But these spectral lines have a doublet "fine structure" measured by α^2 — hence the name. This fine structure was computed by Sommerfeld in 1916, and in an apparently different way by Dirac in 1929. The next correction is called the "Lamb shift" and involves α^3, but by the time one tries to compute α^4 effects both the strong and the weak interactions have to be taken into account. At this point one needs to calculate millions of terms, which means that even the algebra has to be done on super computers. Hence in our view QED is defended by four rings of fortifications — the effects proportional to α, α^2, α^3, α^4. Each class of effects is about a hundred times smaller than the last, and usually much more than a hundred times harder to calculate.

Conventional calculations have succeeded in achieving agreement with experiment for many effects of order α^3 and some of order α^4. Models of both the weak and the strong interactions generalized from QED have had some striking successes — thanks to a generous input of empirical data. The success was bought by considerable technical complexity. The fine structure constant measures the probability of emission and absorption of radiation; yet when the same particle emits and absorbs this radiation, the effect is infinite. Such effects can be made finite by adding additional infinite terms to the theory crafted to cancel the calculated infinities; this process is called "renormalization". Sophisticated "non-Abelian gauge theories" have recently bounded this confusion at the cost of predicting a "vacuum" energy density 10^{120} times too large to meet the cosmological requirements. Herculean efforts are needed to keep the (model) universes from shutting themselves down before they can gasp. We are plagued by none of these difficulties.

Assuming that the conventional theorist has successfully found his way through the mine field described in the last paragraph, he still has difficulty properly connecting the basically non-relativistic (low velocity) model of the hydrogen atom (Bohr or Dirac) to these very high (virtual) energy effects. A current problem for him is "positronium". Positronium is an atom made up of the familiar negatively charged electron and its positively charged "anti-particle", the positron. Together they annihilate, and "all is gamma rays" (like when the Teller and the anti-Teller meet), but before this happens, they emit light (spectral lines) which Bohr could compute; a first approximation to the fine structure can be obtained by following Sommerfeld or Dirac. But this is not enough. One way the bound state problem shows up is that α^3 terms in the calculation of the decay lifetime of positronium have not yet been articulated. They would have to be a hundred times larger than expected in order to explain the experimental results. This fact in itself shows that the conventional method of calculation is breaking down: even the α^2 term is suspiciously large.

Trouble now exists close to the heart of quantum field theory. This fact became manifest at an auspicious time for us. Thanks to McGoveran[34], we have already breached the second (α^2) line of defense surrounding QED. Some mopping up operations are still needed; a lot of technical development will have to be carried out before we can tackle positronium directly. The significant fact is that *we now know how to make relativistic bound state calculations* in a simple way. Apparently all that is needed is a lot of hard work. I now raise the cry: On to QED! Seize the time!

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Summary of **WHERE WE ARE**

General structural results

- 3+1 asymptotic space-time
- transport (exponentiation) operator
- combinatorial construction of π
- limiting velocity
- supraluminal synchronization and correlation *without* supraluminal signaling
- discrete events
- discrete Lorentz transformations (for event-based coordinates)
- relativistic Bohr-Sommerfeld quantization
- non-commutativity between position and velocity
- conservation laws for Yukawa vertices and 4- events
- crossing symmetry

Gravitation and Cosmology

- the equivalence principle
- electromagnetic and gravitational unification
- the three traditional tests of general relativity
- event horizon
- zero-velocity frame for the cosmic background radiation
- mass of the visible universe: $[2^{127}]^2 m_p = 4.84 \times 10^{52}\ gm$
- fireball time: $[2^{127}]^2 \hbar / m_p c^2 = 3.5$ million years
- critical density: of $\Omega_{Vis} = \rho/\rho_c = 0.01175$ $[0.005 \leq \Omega_{Vis} \leq 0.02]$
- dark matter= 12.7 times visible matter [10??]

Unified theory of elementary particles

- quantum numbers of the standard model for quarks and leptons
- gravitation: $\hbar c / G m_p^2 = 2^{127} + 136 = 1.70147... \times 10^{38}$ $[1.6937(10) \times 10^{38}]$
- weak-electromagnetic unification:
  $G_F m_p^2 = 1/[256^2 \sqrt{2} m_p^2] = 1.07896 \times 10^{-5} m_p^{-2}$ $[1.02684(2) \times 10^{-5}]$;
  $sin^2\theta_{Weak} = 0.25$ $[0.0229(4)]$
- the quark-lepton generation structure
- generations weakly coupled with rapidly diminishing strength
- color confinement — quark and gluon masses not directly observable
- $m_{u,d}(0) = \frac{1}{3} m_p$
- the hydrogen atom: $(E/\mu c^2)^2 [1 + (1/137 N_B)^2] = 1$
- the Sommerfeld formula: $(E/\mu c^2)^2 [1 + a^2/(n + \sqrt{j^2 - a^2})^2] = 1$
- the fine structure constant: $\frac{1}{\alpha} = \frac{137}{1 - \frac{1}{30 \times 127}} = 137.0359674...[137.035963(15)]$
- $m_p/m_e = \frac{137\pi}{\frac{3}{14}\left(1+\frac{2}{7}+\frac{4}{49}\right)\frac{4}{5}} = 1836.151497...$ $[1836.152701(100)]$
- $m_\pi \leq 274 m_e$: $[m_{\pi^\pm} = 273.13 m_e,\ m_{\pi^0} = 264.10 m_e]$

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