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T, Noyes

DISCRETE ANTI-GRAVITY*

H.PIERRE NOYES

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

and

SCOTT STARSON

STARSON Corporation

ABSTRACT

Discrete physics, because it replaces time evolution generated by the energy operator with a global bit-string generator (*program universe*) and replaces "fields" with the relativistic Wheeler-Feynman "action at a distance", allows the consistent formulation of the concept of signed gravitational charge for massive particles. The resulting prediction made by this version of the theory is that free anti-particles near the surface of the earth will "fall" up with the same acceleration that the corresponding particles fall down. So far as we can see, no current experimental information is in conflict with this prediction of our theory. The *experiment crusis* will be one of the anti-proton or anti-hydrogen experiments at CERN. Our prediction should be much easier to test than the small effects which those experiments are currently designed to detect or bound.

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Although this century has witnessed two basic revolutionary developments in physics, usually referred to as relativity and quantum mechanics, reconciliation between these two radical departures from conventional thinking has been hard to achieve. By now most particle physics theorists believe that non-abelian gauge theories — a very narrow sector of the overlap between quantum mechanics and *special* relativity— remove the infinities that more naive approaches invariably produce. Nevertheless a distinguished physicist and philosopher[1] can still say that he is uninterested in comparing *relativistic* quantum mechanics with experiment because it does not have a rigorous mathematical basis. It is widely believed that the problem of achieving a quantum theory of gravitation, which most physicists would think of as the reconciliation between quantum mechanics and *general* relativity, has yet to be achieved. For example, in his lectures at Schladming in March, 1991 C.J.Isham gave a survey of some of these difficulties and asserted that he finds a basic incompatibility between the foundations of quantum theory and general relativity.

The situation is significantly different with regard to the compatibility between the basic phenomena on which belief in relativistic particle kinematics and relativistic quantum particle mechanics rests. These phenomena can be formalized and reconciled if one is willing to adopt a novel approach to the problem. We model particle physics and physical cosmology by constructing "space", "time", and "particles" using a finite and discrete set of concurrent computer operations rather than trying to embed discrete quantum events in a pre-existing continuum. One can characterize the theory by a modern version of the older materialist slogan, — "Chance, events and the void suffice." This work started back in the 1950's with research by Bastin and Kilmister and in collaboration with Amson, Pask and Parker-Rhodes led them to the discovery of the *combinatorial hierarchy*[2] in 1961. A preliminary connection to particle physics[3] was presented in 1979. However, it was not until 1987 that HPN was prepared to claim[4] that this research program had indeed led to a reconciliation between quantum mechanics and (special) relativity.

Discrete Physics, or "bit-string physics" as it is sometimes called, draws on computer science and constructive mathematics for many of its basic ideas.[5] That there were obvious connections to gravitation has been known since 1961 when Bastin pointed out (Ref. 2) that the last two terms in Parker-Rhodes' 4-level terminating combinatorial hierarchy (3, 10, 137, $2^{127}+136$) are suggestively close to the dimensionless scale constants $\hbar c/e^2 \approx 137$, $\hbar c/Gm_p^2 \approx 1.7 \times 10^{38}$. The connections were made still closer once the construction of relativistic quantum mechanics and physical cosmology had been sketched out[6] and the theory had been shown to imply the three classical predictions of *general* relativity[7]. More recently it has become possible to discuss the relationship between our approach to the gravitational problem[8] and work by Wheeler[9] based on the entropy of charged, rotating black holes.

Although *discrete physics* has had considerable success in calculating masses and coupling constants that are already known (see *Predictions*, following references), many of which cannot be calculated by conventional theories, so far a numerical prediction prior to experimental measurement has not been possible. We came close to being ready to predict that the width of the Z^0 would limit the number of types of neutrinos to the three used in the current version of the standard model for quarks and leptons. After the SLAC measurements started to come in, we realized that there is only room for three generations at the level of $1/256^4$ coupling, a statement that could not be made within the standard framework.

The encounter between the authors of this paper at PIRT II (the conference where Ref. 8 was presented) has opened up a radically different way in which our approach could be tested. In a paper prepared for PIRT II, shown to HPN but not formally presented, and in private discussions, SS gave strong arguments for the discreteness of physical processes at the Planck length (which is one way of looking at discrete physics), and for abandoning the equivalence principle. The testable conclusion was that, as stated in our abstract, the anti-proton[10,11] and anti-hydrogen[12–15] experiments now being prepared or proposed at CERN should show that anti-protons and anti-hydrogen "fall" up with the same acceleration that protons and hydrogen fall down. This should be much easier to demonstrate than the small departures from conventional theory that these experiments are currently designed to detect or bound. One purpose of this paper is to encourage the experimenters to try a preliminary run before all the refinements needed for high precision are in place.

As we discuss in greater detail in FDP and DP, we view the task of theoretical physics as an application of a general *modeling methodology* in which we start with a rough idea of the phenomena we wish to model (in our instance laboratory physics and observational cosmology *as practiced*), construct a representation which can be given logical and mathematical precision, and then introduce rules by which this quantitative structure can be compared with laboratory phenomena already available or carried out to test the expected consequences. We are prepared to repeat this cycle — or variants of it — many times before we achieve a satisfactory model. In the spirit of Bridgman, we try to make our basic *rules of correspondence* between the mathematical structure and actual laboratory practice as direct and simple as possible.

We start by using the *counter paradigm* (see DP) to connect the SI units of length and time to the corresponding length and time intervals in our bit-string model. Consider two counters a distance L apart which fire sequentially with a time interval T between the two firings. We model these two events by two independently generated[16] *bit-strings*, which when compared by *discrimination* (similar to the XOR operation of computer practice) produce a string with $r + \ell$ symbols, r of them being "1" 's and ℓ of them being "0" 's. Our rule of correspondence is that the distance interval between the counters is given by $L = (r - \ell)(h/mc)$ and the time interval between the firings is $T = (r + \ell)(h/mc^2)$. We are now under the obligation to give separate operational meaning to the symbols c, h and m. Implicit in our paradigm is the assumption that the uncertainties in distance and time measurements are much greater than h/mc and h/mc^2 respectively. This is currently true for *direct* measurements of the type described in the paradigm.

We define "velocity" by $V := \beta c := L/T$. The symbol "c" is referred to as the *limiting velocity.* It represents the empirical generalization that no experiment where proper care was exercised in the elimination of background has given sequential counter firings for which this limit for L/T was exceeded. This experience is now codified in SI units by defining "c" as the *integer* $c := 299\ 792\ 458\ ms^{-1}$.

To obtain h/m, we prepare a beam of particles of constant velocity βc (with $\beta << 1$) incident on a pair of slits a distance d apart and measure the spacing s between the interference maxima in a counter array perpendicular to the beam line from the slits to the array at a distance D behind them. Then $h/m := \beta c(sd/2D)$. The invariance of this number for a given type of particle beam over a large range of velocities and in various geometries summarizes current experience. If we can prepare different types of particle beams with the same velocity incident on the same geometrical arrangement used to measure h/m, we can define and measure mass ratios by $m_1/m_2 := s_2/s_1$. In most of particle physics, it is convenient to use either the proton mass m_p or the electron mass m_e as the reference mass, particularly since there is no empirical evidence that either is unstable. Intercomparison is achieved by an overall fit to all data considered relevant, with the current result[17] $m_p/m_e = 1836.152\ 701(37)$.

Our specification of mass ratios is not a conventional one. An alternative that is available to us is to allow two constant velocity particle beams $[V_1, V_2]$ with relative angle θ to cross each other and scatter into relative angle ϕ with velocities $[V_1', V_2']$. Within experimental uncertainties, initial and final velocities lie in a plane. Further, for any reference direction in that plane such that $\theta_1 - \theta_2 = \theta$ and $\phi_1 - \phi_2 = \phi$, we find that given sufficient and sufficiently precise data we can always determine two masses (relative to some arbitrary, finite reference mass) such that $m_1 V_1 cos\ \theta_1 + m_2 V_2 cos\ \theta_2 = m_1 V_1' cos\ \phi_1 + m_2 V_2' cos\ \phi_2$. All these statements are, of course, subject to appropriate qualifications about experimental uncertainties, and the allowed range of the parameters. They are equivalent to Mach's definition of mass ratios starting from Newton's Third Law. We cannot accept his starting point because it is *scale invariant*, while our fundamental paradigm breaks scale invariance by invoking a unit of length (time) which is h/mc (h/mc^2). We abandon Mach's definition in favor of the definition provided above in terms of particulate quantum interference. We have argued elsewhere that we can derive Mach's specification of mass ratios from our discrete model[18]. This conclusion follows in our model because events involving constant velocity particles can occur only at "points" separated by an integral number of wavelengths $\lambda = h/\beta mc$.

The careful reader will note that our definition of mass ratios imposed the "non-relativistic" restriction $|\beta| << 1$. So far as we know, there are no *interference* experiments that distinguish the non-relativistic deBroglie wavelength $h/\beta cm$ from the relativistic deBroglie wavelength $h/\gamma\beta cm$, with $\gamma^2\beta^2 = \gamma^2 - 1$. David Fryberger, Pat Suppes and HPN are investigating whether current technology might allow this statement to be revised. The modified definition of mass ratios is obvious and immediate. The experimental decision between the relativistic and non-relativistic alternatives could provide an *experiment crusis* separating alternative relativistic and non-relativistic quantum mechanical models.

We have taken care to spell out what we mean by "mass ratios" in our theory because the fusion of the concept of "inertial mass" with "gravitational mass"— the "equivalence principle" — was Einstein's starting point in constructing the general theory of relativity. From his point of view, the interesting part is yet to come. For us, the concept of "mass" stops with what he (and Newton) would call "inertial mass", — mass ratios measured by conservation of momentum in collisions, and in our quantized theory by deBroglie wave interference. We have discussed elsewhere[19] how our bit-string theory can accept the macroscopic "field" concept of classical physics as a continuum approximation to our discrete theory. Here we take a more radical stance by bringing to the fore aspects of discrete physics that suggest a fundamental conceptual break with continuum physics and allow us to abandon both the concept of "energy" and the "equivalence principle" at the same time. Whether or not our prediction proves to be correct, we believe that the issue we raise of the incompatibility between the ***CPT*** invariance of the theory and the equivalence principle deserves careful investigation in any framework that the reader accepts for his own work.

Our discussion of "gravity" follows from our understanding of electromagnetic interaction in our model, and our successful calculation of both the fine-structure spectrum of the hydrogen atom and the *value* of the fine-structure constant[20]. The tentative interpretation of the third combinatorial hierarchy constant $137 \approx \hbar c/e^2$ as the number of events which provide the "background" for each "Coulomb event" that keeps the atom bound is reinforced by our derivation of the *relativistic* Bohr formula[21] from this starting point. Including a second degree of freedom leads to the Sommerfeld formula[22] and a combinatorial correction to the fine structure constant which brings it close to the accepted empirical value. In conventional renormalized QED, the first calculation amounts to calculating the binding energy in the Coulomb gauge, and the second to including the spin-dependent corrections of order $1/137$. This suggests that in our theory the particulate states of two particles bound gravitationally will have the Bohr spectrum with coupling constant $\frac{Gm_p^2}{\hbar c}(\frac{m_1 m_2}{m_p^2}) \approx \frac{m_1 m_2}{m_p^2}/1.7 \times 10^{38}$ replacing $1/137$. Such particulate bound states have yet to be observed, except for aggregates of matter so large as to overcome the very small coupling constant and to make the quantum levels unobservable. That quantum mechanics nevertheless applies to gravitation was demonstrated by quantum interference effects involving *single* neutrons near the earth. From our point of view, "spin-dependent" corrections can be expected to be smaller by 1.7 parts in 10^{38}, which enormously simplifies our analysis of the anti-proton experiment.

Whether or not the force between two particles is attractive or repulsive is most simply established by whether or not they form a bound state. This was the starting point for the Bohr atom, which assumed that — as was known for macroscopic charged objects — elementary particles of opposite charge would attract each other, and of the same charge repel each other. In scattering states either attractive or repulsive electric forces for particles with positive energy lead (classically) to hyperbolic orbits, the only difference being which focus of the hyperbola the reference particle occupies. This difference is not directly observable at the atomic level. However, the short range nuclear force, which has to be attractive in order for nuclei to form, can interfere with the coulomb force in the scattering of like charges (eg. proton-proton scattering) and hence confirm the assumption that the electric force between these two like charges is indeed repulsive. No known phenomenon would lead us to question the assumption that like electric charges repel and unlike charges attract at the particulate level.

The situation for gravitation differs in that no elementary particle states which are bound gravitationally have been observed, or can be expected to be observed with currently available techniques. Similarly, quantum interference effects between gravitational scattering and known interactions are may orders of magnitude below current detection threshold. That neutrons are attracted by the earth was shown using external reactor beams shortly after World War II, and beautiful cold neutron interference experiments show that this force also has the expected coherent quantum mechanical effects. But to our knowledge there is no *direct* experimental evidence that either anti-neutrons or anti-protons are attracted to rather than repelled by the earth. In this sense the CERN anti-proton and anti-hydrogen gravity experiments offer a unique and clear window through which to look at a basic phenomenon that is otherwise inaccessible.

Since we still lack this experimental information, we next ask what theory would lead us to expect. This is a very complicated question in conventional relativistic quantum field theories because as already noted there is currently no consensus as to how to formulate a theory of "quantum gravity". In contrast, discrete physics already contains the connection between the proton mass, the Planck mass and Newton's gravitational constant $[\hbar c/Gm_p^2 = (M_{Planck}/m_p)^2 \approx 1.7 \times 10^{38}]$ as a *prediction* of the theory. Further, we have argued above that for particulate experiments only the Newtonian term will be significant. Few physicists would argue with the proposition that like electric charges attract, unlike electric charges repel, and that either two particles or two antiparticles would attract each other gravitationally. What we need is a theoretical argument at to whether a particle would either attract or repel an anti-particle gravitationally. To make the argument, we must first explain how the Coulomb attraction and repulsion arise in discrete physics.

As we have already noted, the hyperbolic scattering trajectories (Rutherford scattering) produced by Coulomb attraction and repulsion are not distinguishable in quantum scattering experiments without further information. However, for a particle-antiparticle pair, there is an additional contribution to the scattering in a *relativistic* quantum theory due to the pair coalescing to make an "off energy shell" or "virtual" photon. This Bhabha term interferes with the Rutherford scattering and is readily observed at high energy, confirming directly the attractive force between particle and antiparticle. However, when particle is changed to antiparticle ("crossing") this term becomes simply one of the two "coulomb exchange terms" which appear in the (repulsive) Coulomb scattering between two identical particles. That this virtual photon is still characterized by zero "rest mass" is the starting point for the "renormalization group equation", — a subject we will approach from the discrete physics point of view in subsequent research. Discrete physics contains all these standard results.

The "crossing symmetry" which is invoked here comes from the $\mathcal{CPT}$ invariance of the theory. In our bit-string model the choice between which of the two dichotomous symbols in the bit-string we call "0" and which "1" is simply a choice between one representation of the combinatorial hierarchy and a distinct dual representation. This property in our context is called Amson invariance, and is discussed on pp 7-10 in a recent technical note[23]. Briefly, we have to interpret our model in such a way that when we interchange "0" 's and "1" 's in a string (the "bar" operation) the fixed ("label") part of the string that contains discrete quantum numbers such as charge has to reverse their sign as well as reversing velocities and reflecting spacial coordinates. Since, other than magnitude and the distinction that like particles attract each other rather than repel, the gravitational interaction in the Newtonian approximation is indistinguishable from the electromagnetic interaction in the Coulomb approximation, we interpret "crossing" or $\mathcal{CPT}$ invariance to require a particle and an anti-particle to *repel* each other gravitationally. *This is our* *prediction.* What remains for us to do is to show that if we accept this prediction, there are no currently observable consequences other than the dramatic prediction of what we expect in the CERN anti-proton and anti-hydrogen experiments.

The easiest question to dispose of is whether or not we expect we expect gravitation to break $\mathcal{CPT}$ invariance in a way that can be observed using current technology. The answer is that it does, at least globally, if we accept the conventional interpretation of cosmological data as showing that the matter of the universe consists primarily of protons, nuclei and electrons rather than anti-protons, anti-nuclei and positrons, and that there are around 2×10^{10} photons per baryon. This small trace of matter is well predicted, to a first approximation, by our theory, as we argue in Ref. 7. The point that is less clear is whether our model for the approximately 12.7 times as prevalent "dark matter" as composed of gravitons, photons, neutrinos and anti-neutrinos gravitationally bound will indeed act gravitationally as matter rather than anti-matter, as it must if it is to explain the observed linear radial doppler shift dependence of the light from galaxies. If neutrinos and anti-neutrinos repel, as we are required to assume for consistency, then our "dark matter" will contain the same trace of matter relative to photons that we have already estimated for electrons and nucleons. So far, this does not seem to cause us any difficulty.

The conventional treatment of gravitation in special relativity starts from the mass-energy equivalence $E = mc^2$ and treats this energy, whatever its cause, as a source of gravitational field. This gives the red shift of light emitted by the sun correctly, but fails by a factor of 2 to explain the displacement of stellar positions near the sun observed during a solar eclipse, and fails by a factor of 6 to explain the observed precession of the perihelion of Mercury. As we argue in Ref. 7, all that is needed to explain these two effects is the spin 1 character of traveling photons and the spin 2 character of traveling gravitons. The full paraphernalia of the Einstein theory is, from our point of view, overkill and should — if possible — be dispensed with by invoking Occam's Razor. The problem we face is whether electromagnetic and gravitational radiation are attracted by matter in our theory.

Since massless radiation cannot carry gravitational charge, we would expect both types of radiation to be attracted by either matter or anti-matter in the same way. Then our explanation of the classical tests of general relativity *and* explanation of "dark matter" as consisting of stable "quantum geons" would still survive. Lacking a full theory of quantum gravity formulated along the line we propose for deriving the classical Maxwell theory as a continuum approximation, we cannot be sure. But we can make a few qualitative arguments.

The basic difficulty in comparing our theory to a theory of gravitation where energy rather than matter is the "source" of the gravitational "field" is that field energy does not appear in our theory. Massive particles have energy and momentum connected in the usual way. They have velocities in the reference frame at rest with respect to the $2.7^o K$ cosmic background radiation which can be modeled by rational fractions lying between -1 and +1, specifically by the difference between the number of "0" 's and "1" 's in a bit string divided by the sum of those numbers. But "massless quanta", apart from their helicity quantum numbers, are modeled simply by the null or the anti-null string and contain no possibility of defining their "energy", "momentum" or "wavelength" other than by context. To indirectly infer these "classical" parameters we *must* model both the "source" and the "sink" of the radiation by the change in velocity of at least two massive, charged particles. In other words we have no choice but to adopt the Wheeler-Feynman "action at a distance" point of view. It is still possible to discuss "photon-photon scattering". This process is studied at SLAC in precisely the way that this description requires, that is by measuring the change in velocity of the source and target particles and any additional charged particles emitted in the process. The photon-photon process itself does not depend on whether the charges and currents which emit and absorb the "photons" are positive or negative. If the treatment of gravitational radiation can be carried through along the same lines, which appears to be possible — but difficult— then the photon-graviton interaction will be independent of whether the source of the gravitational radiation is particles or antiparticles, and all our earlier results will survive.

We conclude that it is possible, and perhaps even likely that the bit-string model of discrete physics can indeed be shown to *predict* that anti-protons will "fall" up near the surface of the earth with the same acceleration that protons and hydrogen fall down.

That the correct starting point for a theory of anti-gravity is the denial of the equivalence principle was originally suggested by SS. That discrete physics might provide a convenient theoretical framework for such a theory was suggested by HPN. We are indebted to M.C.Duffy for bringing us together at the second conference on *Physical Interpretations of Relativity Theory*, and for the stimulating intellectual environment provided by individuals at that conference willing to question established scientific dogma in a systematic way.

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Predictions made by Discrete Physics: March, 1991

For background see papers by H.P.Noyes and D.O.McGoveran: "An Essay on Discrete Physics", *Physics Essays*, **2**, 17-100 (1989) and SLAC-PUB-4528; "Foundations for a Discrete Physics", SLAC-PUB-4526; and "Discrete Gravity", *Physical Interpretations of Relativity Theory, II*, M.C.Duffy, ed., Imperial College, London, 1990, pp 196-201 and SLAC-PUB-5218.

EMPIRICAL INPUT

$c, \hbar$ and m_p as understood in the "Review of Particle Properties", Particle Data Group, *Physics Letters*, **B 239**, 12 April 1990. Numbers are quoted in the format [( )] = empirical value (error) or range.

$^a[G^2_{\pi N} = 13.3(3)$ from R.A.Arndt *et.al.*, . *Phys. Rev. Lett.*, **65**, 157 (1990). F.Sammarruca and R.Machleit (*BAPS*, **36**, No. 4 (1991)) note most modern models for the nuclear force use the strong empirical ρ coupling and therefore require $G^2_{\pi N} > 13.9$; the smaller vector-meson-dominance-model value for ρ is compatible with the Arndt value.]

COUPLING CONSTANTS

Coupling Constant	Calculated	Observed
$G^{-1}\frac{\hbar c}{m_p^2}$	$[2^{127}+136]\times[1-\frac{1}{3\cdot 7\cdot 10}] = 1.693\ 37\ldots\times 10^{38}$	$[1.69358(21)\times 10^{38}]$
$G_F m_p^2/\hbar c$	$[256^2\sqrt{2}]^{-1}\times[1-\frac{1}{3\cdot 7}] = 1.02\ 758\ldots\times 10^{-5}$	$[1.02\ 682(2)\times 10^{-5}]$
$sin^2\theta_{Weak}$	$0.25[1-\frac{1}{3\cdot 7}]^2 = 0.2267\ldots$	$[0.2259(46)]$
$\alpha^{-1}(m_e)$	$137\times[1-\frac{1}{30\times 127}]^{-1} = 137.0359\ 674\ldots$	$[137.0359\ 895(61)]$
$\alpha_s(m_\pi^2)$	$\frac{1}{7} = \frac{m_\pi}{m_N}$	[? ?]
$G^2_{\pi N}$	$[(\frac{2M_N}{m_\pi})^2-1]^{\frac{1}{2}} = [195]^{\frac{1}{2}} = 13.96..$	$^a[13,3(3), > 13.9?]$

MASS RATIOS

Mass ratio	Calculated	Observed
$\left[\frac{M_{Planck}}{m_{proton}}\right]^2 = \frac{\hbar c}{Gm_p^2}$	$[2^{127}+136] = 1.70147\times 10^{38}$	Proton mass is gravitationally generated
m_p/m_e	$\frac{137\pi}{\frac{3}{14}\left(1+\frac{2}{7}+\frac{4}{49}\right)\frac{4}{5}} = 1836.15\ 1497\ldots$	$[1836.15\ 2701(37)]$
$m_\pi^{\pm}/m_e$	$275[1-\frac{2}{2\cdot 3\cdot 7\cdot 7}] = 273.12\ 92\ldots$	$[273.12\ 67(4)]$
m_{π^0}/m_e	$274[1-\frac{3}{2\cdot 3\cdot 7\cdot 2}] = 264.2\ 143\ldots$	$[264.1\ 373(6)]$
m_μ/m_e	$3\cdot 7\cdot 10 = 210$	$[206.768\ 26(13)]$

General structural results

- 3+1 asymptotic space-time
- combinatorial free particle Dirac wave functions
- supraluminal synchronization and correlation *without* supraluminal signaling
- 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, CPT, spin and statistics
- Fields replaced Wheeler-Feynman ' 'action at a distance"

Gravitation and Cosmology

- consistent formulation of gravitational charge
- 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: $(2^{127})\hbar/m_p c^2 = 3.5$ 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??]
- baryons per photon $= 1/256^4 = 2.328\ldots \times 10^{-10}$ $[2 \times 10^{-10}?]$

Unified theory of elementary particles

- quantum numbers of the standard model for quarks and leptons with confined quarks and exactly 3 weakly coupled generations
- gravitation: $\hbar c/Gm_p^2 = [2^{127} + 136] \times [1 - \frac{1}{3\cdot 7\cdot 10}] =$ $1.70147\ldots[1 - \frac{1}{3\cdot 7\cdot 10}] \times 10^{38} = 1.693\ 37\ldots \times 10^{38}$ $[1.693\ 58(21) \times 10^{38}]$
- weak-electromagnetic unification:
  $G_F m_p^2/\hbar c = (1 - \frac{1}{3\cdot 7})/256^2\sqrt{2} = 1.02\ 758\ldots \times 10^{-5}$ $[1.02\ 684(2) \times 10^{-5}]$;
  $sin^2\theta_{Weak} = 0.25(1 - \frac{1}{3\cdot 7})^2 = 0.2267\ldots$ $[0.2259(46)]$
  $M_W^2 = \pi\alpha/\sqrt{2}G_F sin^2\theta_W = (37.3\ Gev/c^2 sin\ \theta_W)^2$; $M_Z cos\ \theta_W = M_W$
- the hydrogen atom: $(E/\mu c^2)^2[1 + (1/137N_B)^2] = 1$
- the Sommerfeld formula: $(E/\mu c^2)^2[1 + a^2/(n + \sqrt{j^2 - a^2})^2] = 1$
- the fine structure constant: $\frac{1}{\alpha} = \frac{137}{1 - \frac{1}{30\times 127}} = 137.0359\ 674\ldots$ $[137.0359\ 895(61)]$
- $m_p/m_e = \frac{137\pi}{\frac{3}{14}\left(1+\frac{2}{7}+\frac{4}{49}\right)\frac{4}{5}} = 1836.15\ 1497\ldots$ $[1836.15\ 2701(37)]$
- $m_\pi^\pm/m_e = 275[1 - \frac{2}{2\cdot 3\cdot 7\cdot 7}] = 273.1292\ldots$ $[273.12\ 67(4)]$
- $m_{\pi^0}/m_e = 274[1 - \frac{3}{2\cdot 3\cdot 7\cdot 2}] = 264.2\ 1428..$ $[264.1\ 373(6)]$
- $\alpha_s(m_\pi^2) = \frac{1}{7}$
- $(G_{\pi N}^2 m_{\pi^0})^2 = (2m_p)^2 - m_{\pi^0}^2 = (13.868..\ m_{\pi^0})^2$