ELEMENTARY PHYSICS

IN THE CELLULAR AUTOMATON UNIVERSE

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Abstract

General relativity is a mathematical model that uses sophisticated geometry to describe simple physics. It agrees with experiment in the few tests that can be made, but the whole edifice is not physics. Instead of using observations to test that model, I derive a simple empirical model of elementary physics and cosmology from the observations. The observations imply that the universe is a finite cellular automaton; that there is no curved space; that fundamental particles are massless; that "massy" particles, including electrons, are composed of fundamental particles; that gravitational mass is inertial mass; that black holes are made from neutrons compressed into bosons; that the universe was produced from cold compressed particles, not radiation; and that the universe is not expanding.

GRAVITY

A physical "law" on which people seem to agree is that the speed of light is constant to all observers, that massless particles move at the speed of light in vacuum, and that massy particles have the speed of light as an unreachable upper limit to their velocities. This should be the starting point of our physics instead of the customary historical development. The law implies that physics is "digital" instead of "analog" and that the speed of light is some kind of unit. The easiest explanation is that the universe is a cellular automaton† and that the speed of light is the ratio of the space step to the time step. At every clock tick everything moves or shifts one step. There are no such things as continuity, or points, or singularities, or infinity in physics. These are mathematical concepts that are used in mathematical modelling of physics, but they are not physics.

Any fundamental particle must move at the speed of light because that is the only speed possible in the cellular automaton, one space step per tick, and therefore a fundamental particle must be massless.

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†A cellular automaton is a lattice of discrete identical sites, each taking on a finite set of values. The values evolve in discrete time steps according to rules that specify the value of each site at the next time step in terms of the values of neighboring sites now (cf. Wolfram 1994). This paper is not based on the work of Wolfram or of anyone else. The first draft was written in January 1975.

Composite particles are combinations of fundamental particles. Since massy particles move at less than the speed of light, massy particles must have an internal structure of massless particles that move at the speed of light but that execute internal motions in the massy particles so that the net velocity is less than the speed of light. The need to perform internal motions prevents a massy particle from ever moving as fast as the speed of light no matter how much it is accelerated.

If massy particles are made from massless particles, then mass does not exist. What we perceive as mass is just inertial mass equal to the momentum divided by the velocity. All particles have inertial mass.

If massy particles are made from massless particles, then gravity cannot depend on mass, but instead on inertial mass, which is identical to gravitational mass, and is equal to the momentum divided by the velocity. All particles have gravitational mass. All particles are affected by gravity and attract each other.

If a plausible minimum time in particle physics is $\sim 10^{-28}$s, the cell size in the cellular automaton would be $\sim 3\times 10^{-18}$ cm, about 10000 cells in a classical electron radius. Discussion of a cellular automaton model of the universe is given at the end of this paper. At low resolution, down to nuclear dimensions, the special relativity model of physics works well with continuous space-time and continuous Lorentz transformations. However as v/c approaches unity at very high energies the granularity must become apparent in all relativistic effects.

Since the universe is filled with particles and massive bodies, no particle or body can travel in a straight line for any significant length of time. Particle paths are always longer than they seem naively. Massless particles may seem to be slowed by gravity in traveling between two points but the massless particles always travel at the speed of light over a longer path. If a massless particle is passing through plasma, or gas, or liquid, or a solid, its velocity does not change; its path wobbles on a microscopic scale so that the distance traveled is greater.

General relativity is a mathematical model that uses sophisticated geometry to describe simple physics. It is not physics. There is no such thing as curved space. Space is not a physical concept since the cellular automaton is complete in itself. Many real results of general relativity can be obtained using simple empirical arguments. Below are the standard observations from which the properties of gravity can be derived. Calculations can be made with a continuous mathematical models because the scales are so large. After the discussion of gravitation, additional sections on particle physics and cosmology are meant to suggest the new physics required. As I am not capable of doing it, I leave it to the readers to work out the cellular rules for their favorite particles and to correct my guesses about the cellular automaton structure.

The Precession of the Perihelion, or The Deflection of a "Massy" Particle

Mercury orbiting the Sun is the standard example where the observed precession is 13.489"/orbit mostly from precession of the observer's coordinate system and from interactions with other bodies in the solar system (cf. Misner, Thorne, and Wheeler 1973, p.1113). Only 0.104"±0.002"/orbit of the precession is produced by integration over the volumes of Mercury and the Sun and non-radial relativistic effects (Shapiro et al. 1972). But since we do not yet know the internal structure of Mercury (or the Sun), the precession of Mercury is not a test of relativity. In fact the density distribution in Mercury can be estimated by requiring that it produce most of the observed precession. In distance, the precession of the perihelion is about 29 km/orbit.

The gravitational field produced by a composite particle or larger body varies with velocity and has the same properties as the electric field produced by a moving electric point charge that is described in electricity and magnetism textbooks. From Resnick (1968) substituting GM for $q/4\pi\epsilon_0$,

$$\vec{f} = (1-\beta^2)/[1-\beta^2 \sin^2\alpha]^{3/2}\ GM\hat{r}/r^2, \tag{1}$$

where $\beta = v/c, v$ is the particle velocity, c is the speed of light, α is the angle between $\hat{v}$ and $\hat{r}$, G is the gravitational constant, and M = $M_0/(1\text{-}\beta^2)^{1/2}$ is the gravitational mass. The field moves away from the poles, the direction of motion, toward the equator as the velocity increases. The $\alpha\beta$ factor is $(1-\beta^2)$ at the poles which goes to 0 as v approaches c. The $\alpha\beta$ factor is $1/(1-\beta^2)^{1/2}$ at the equator which becomes large as v approaches c. Substituting $\sin^2 = 1\text{–}\cos^2 = 1\text{–}(\hat{v}\cdot\hat{r})^2$,

$$\vec{f} = (1-\beta^2)/[1-\beta^2(1-(\hat{v}\cdot\hat{r})^2]^{3/2}\ GM\hat{r}/r^2. \tag{2}$$

The integral of the force over the volumes of Mercury and the Sun does not degenerate into a two-body problem but it can be treated as a two-body problem in heliocentric coordinates with perturbations. The subscripts S and M refer to the Sun and Mercury.

$$\vec{F} = -GM_M(M_\odot + M_M)(1-v^2/c^2)/[1-v^2/c^2(1-(\hat{v}\cdot\hat{r})^2]^{3/2}\ \hat{r}/r^2, \tag{3}$$

where $\hat{r}$ and $\hat{v}$ are the position and velocity of the center of mass of Mercury relative to the position and velocity of the center of mass of the Sun, which are defined to be 0. The two-body force is purely radial. The acceleration toward the Sun is $\vec{a} = \vec{F}/M_M$. Typical values in this problem are: period 88 days, r = 0.387 AU or 58 million km; v = 48 km/s; β = 0.00016; $1-\beta^2$ = 0.999999974; M_{0M} = 3.3×10^{26} g; $M_{0M}/M_\odot$ = 0.000000166; M_M = $1.0000000128\times3.3\times10^{26}$ g; $\hat{v}\cdot\hat{r}$ = -0.20 to +0.20.

The perturbative forces are defined at the same time and positions as the two-body force, at the center of mass of the Sun and the center of mass of Mercury. Define $\vec{r}_S$ and $\vec{v}_S$ as the position and velocity vectors of a mass element in the sun relative to the center of the Sun and $\vec{r}_M$ and $\vec{v}_M$ are the position and velocity vectors of a mass element in Mercury relative to the center of mass of Mercury. Let $\vec{d} = \vec{r} + \vec{r}_S + \vec{r}_M$ and $\vec{w} = \vec{v} + \vec{v}_S + \vec{v}_M$. Mercury and the Sun are far apart so they present small solid angles to each other. Assume that the Sun is spherical with radially varying density ranging from 0 to 148 g/cm^3. Assume that the Sun rotates with a surface equitorial velocity of about 2 km/s and that internal motions are smaller than 2 km/s and symmetric about the equator. In the solar part of the integrand of the force, angular effects and retardation effects are small (which I have tested by numerical integration) so that $\vec{r}_S$ and $\vec{v}_S$ can be ignored and the solar part of the integrand can be factored out. Assume that Mercury is spherical with radially varying density. The rotation of Mercury is small and internal motions are small or non-existent so $\vec{v}_M$ is small and $\vec{w} = \vec{v}$. The radius is 2440 km and the density varies from about 3 to more than 9 g/cm^3. The force reduces to

$$\vec{F} = -GM_M(M_\odot + M_M) \int_M (1-v^2/c^2)/[1-(v^2/c^2)(1-(\hat{v}\cdot\hat{d})^2]^{3/2} \rho_M \; \hat{d}/d^2 dV_M/M_M \qquad [4]$$

where $\vec{d} = \vec{r} + \vec{r}_M$ and where all the mass points are retarded to the center of mass of Mercury. The retardation in time is $dt = -(d-r)/c$, and in position is $\vec{d}\,' = \vec{d} - \vec{v}(d-r)/c$. This force has non-radial components. Since β is small the denominator can be expanded to yield

$$\vec{F} = -GM_M(M_\odot + M_M) \int_M [1+{}^1\!/_2\beta^2 - {}^3\!/_2\beta^2(\hat{v}\cdot\hat{d})^2] \; \rho_M \; \hat{d}/d^2 \; dV_M/M_M. \qquad [5]$$

I approximately computed the precession as follows: First the orbit was computed as a two-body problem with [3] using Butcher's 5th order Runge-Kutta method following Boulet (1991) for 50000 steps/day. The perihelion was determined by 6-point Lagrangian differentiation. The two-body orbit repeated the perihelion to 100 μarcsec. A vectorial correction factor to the two-body force for the volume of Mercury was tabulated five times per day for that orbit by integrating [5] over 500 density shells, 500 latitudes, and 1000 longitudes for a range of Mercury models. The precession for a uniform density of 5.426 g/cm^3 was 0.117"/orbit. An iron-core-with-frosting model that I made up inspired by a figure in Schubert et al. (1988) yielded a precession of 0.107"/orbit. Thus, using only special relativity, a simple model reproduces the precession to within 3 percent. I tried ad hoc fixes to the model until a precession of 0.105"/orbit was achieved in agreement with observation. Remember that other small volume effects in Mercury and the Sun were ignored in this calculation; neither is actually spherical. Seismic measurements on Mercury itself will eventually allow a real model to be determined that will test the relativistic calculation.

The Deflection of Starlight, or The Deflection of a "Massless" Particle

The gravitational field expands from a particle at the speed of light. But a "massless" particle moves at the speed of light. In the direction of motion there can be no gravitational field. In analogy with the relativistic contraction of the field of a massy particle described above, the whole gravitational field of a massless particle is in the plane perpendicular to the direction of motion. Instead of filling a solid angle 4π, the field contracts to the "width" of the equator $d\phi$ with solid angle $2\pi d\phi$ and "strength" S. Then $S2\pi d\phi = 4\pi$ and $Sd\phi = 2\delta_\perp$ where $\delta_\perp$ is a δ-function in the equatorial plane. The gravitational mass of a photon, or other massless particle is $2\delta_\perp \mathrm{E}/\mathrm{c}^2$. The gravitational mass averaged over all directions is E/c^2 and the momentum of a massless particle is $(E/c)\hat{c}$.

A massless particle gains energy, blueshifts, as it approaches a massive body B and loses energy, redshifts, as it departs. The gain in energy is also a gain in mass. The gravitational mass M_E is $E/c^2 = (1 + GM_B/r/c^2)E_{r=\infty}$.

The two-body force on a massless particle passing a massive body B in B-centric coordinates is

$$\vec{F} = -GM_B M_E \; 2\sin\alpha \; \hat{p}/r^2 \qquad [6]$$

$$\vec{F} = -GM_B M_E \; 2\sqrt{1-(\hat{c}\cdot\hat{r})^2} \; \hat{p}/r^2$$

where $\hat{r}$ is the vector from the center of mass of B to the massless particle, α is the angle between $\hat{r}$ and $\hat{c}$, and $\hat{p}$ is perpendicular to $\vec{c}$, $\hat{c}\cdot\hat{p} = 0$, and lies in the plane defined by $\vec{c}$ and $\vec{r}$. The acceleration is $\vec{a} = \vec{F}/M_E$. The general case for an extended body B with internal motion is

$$\vec{F} = -GM_E \; 2\int_B \rho\sqrt{1-(\hat{c}\cdot\hat{d})^2} \; \hat{p}/d^2 \; dV. \qquad [7]$$

where $\vec{d} = \vec{r} + \vec{r}_B$ and the mass points are retarded to the center of mass of B, $\hat{r}_B$ and $\vec{v}_B$ are the position and velocity vectors of a mass element in B relative to the position and velocity of the center of mass of B which are defined to be 0. Here $\hat{p}$ is perpendicular to $\vec{c}$, $\hat{c}\cdot\hat{p} = 0$, and lies in the plane defined by $\vec{c}$ and $\vec{d}$. The retardation in time is $dt = -(d-r)/c$, and in position is $\vec{d}\,' = \vec{d} - \vec{v}_B(d-r)/c$.

There are no observations of deflection by point masses. The observations are of lensing by ill-defined bodies far away and lensing by the sun. The solar observations are that photons from a distant star or planet are deflected by 1.751±0.002 $R_\odot/R_{min}$ arcsec (Robertson, Carter, and Dillinger, 1991) as they pass the Sun and are observed at the earth, where R_{min} is the closest approach of the photon to the center of the Sun. There are also observations that show that the pathlength for radar echos from the planets to the Earth increases when the path passes near the Sun relative to when it is further away from the Sun. Shapiro et al. (1971) measured a maximum effect of about 180 μs or 60 km for Earth-Venus-Earth radar echos.

I approximately computed the deflection as follows: The orbit was computed as a two-body problem with [7] using Butcher's 5th order Runge-Kutta method following Boulet (1991) with the constraint that $v = c$. The time step was 0.005 s near the sun and increased outward, and the path ran from -42 million km at Venus to +150 million km at the Earth passing the limb of the Sun at 700000 km. The Sun was modelled as a sphere with no internal motions, so no retardation. The radial density distribution was interpolated from Lebretton and Dappen (1988), normalized to the solar mass, and the force was integrated over 500 density shells, 250 latitudes (in a hemisphere), and 1000 longitudes. I integrated the force over the volume at each step and corrected the two-body force. The deflection was found to be 1.751 $R_\odot/R_{min}$ arcseconds in agreement with observation. Actually the same deflection is found by treating the Sun as a point mass, but the force is slightly weaker near the Sun and slightly stronger far away. Thus the deflection of photons is an effect of special relativity.

The time delay of radar echos can be explained without general relativity. The path for Earth-Venus-Earth radar is rather complicated. A beam of small solid angle leaves the radar on the surface of the Earth. The beam travels about 640 light seconds, 192 million km, and is deflected 1.751 $R_{\odot}/R_{min}$ arcseconds by the Sun along the way. At Venus the deflection is 1629 $R_{\odot}/R_{min}$ km compared to a radius of 6070 km. The beam hits Venus and is backscattered by roughness on the surface integrated over the area of the beam as a function of time. A small amount of backscatter travels back to the radar on Earth and its path is deflected by 1.751 $R_{\odot}/R_{min}$ arcseconds in passage. Meanwhile the radar receiver on Earth has orbited and rotated for 1280 s, about 40000 km, which is about 40 arcseconds seen from Venus. This round trip yields a measurement of the elapsed time to the detection of the beginning of the return pulse out of the noise. Consider a hypothetical measurement where there is no deflection, and where the beam hits the exact center of the disk of Venus and is circularly symmetric. The backscatter to the radar on Earth will measure a time and distance that are a bit longer than the distance to the centerpoint. These hypothetical times are less than the actual observed times. The conclusion is that the real measurement is an integration over area that delays the detectable onset of the return pulse by up to 180 μs or 60 km round trip. The effective surface includes enough of the hemisphere to be up to 30 km beyond the centerpoint.

Orbits of Binary Stars

Binary pulsars are assumed to lose energy through gravitational radiation (Weisberg and Taylor 1984) and to be a test of general relativity. However, there are energy loss mechanisms that can be treated only empirically or semiempirically at the present time that would affect the period. Because of the additional effects, observations that match theory perfectly make me very uneasy.

A neutron star can be crystallized or partially crystallized so that the neutron spins are aligned and the star becomes piezomagnetic. In a binary there is a piezomagnetic tide that varies the magnetic field and generates low frequency electromagnetic radiation. There is also a tide in the plasma around the stars that generates radiation. In fact the universe should be flooded with low frequency electromagnetic radiation from neutron stars in binaries.

A close binary has a reflection effect that heats the substellar point of each star. Each star focuses the radiation from its companion on to itself. The radiative acceleration between the stars decreases the gravitational force pulling them together. Both stars become more luminous and the envelope structure of each star responds to the additional energy with flows and mixing and winds. Tides become more complicated.

Since gravitational force is so much simpler than electromagnetic force, i.e. the cellular rules for gravity are simple compared to the cellular rules for charge, I see no need to postulate the existence of gravitational radiation.

Cosmological Redshift

A particle that travels any distance interacts with the background particles that it passes, gravitationally, electromagnetically, and through every kind of interaction possible. The passing particle, throughout its light cone, participates in the determination of the cellular motion of the background particles. The background particles in the future light cone participate in the determination of the cellular motion of the passing particle. Energy from the passing particle "heats" the background particles. A moving particle loses energy. Photons and neutrinos are redshifted. Cosmic rays lose energy. The redshift is determined by integration along the path. The redshift is not rigorously a measure of distance or of time, but it is roughly proportional to distance and to time if the background density is statistically uniform in space and time. The cosmological redshift is actually a "cellular" redshift. The universe is not expanding.

Photons follow indeterminate, irreproducible paths. In special relativity photon paths are used to measure relative space and time. But in physical special relativity the paths are "fuzzy" so measurements of relative space and time are "fuzzy" as well. Special relativity is a mathematical approximation to the real physics.

FUNDAMENTAL PARTICLES

Particles have complicated cellular automaton rules that involve many space cells and perhaps past and future (i.e. time derivatives). Each type of particle has its own set of rules. Charge, spin, charm, strangeness, etc., are cellular automaton rules.

If massy particles are made from massless particles, then particle physics must be modified. Electrons and protons must be composed of massless particles. Quarks must be massless. Since a neutron can be made from a proton and an electron, it follows that an electron is composed of an anti-up-quark, a down-quark, and an electron neutrino.

The fundamental particles are the six quarks and the three neutrinos and their antiparticles as shown in the table. They all have spin 1/2 so are fermions. All other particles are composite. [The name of τ is regularized to tauon.]

Fundamental Massless Particles

charge	low energy		medium energy		high energy	
+2/3	u	up	c	charm	t	top
+1/3	$\bar{\text{d}}$	anti-down	$\bar{\text{s}}$	anti-strange	$\bar{\text{b}}$	anti-bottom
0	$\bar{\nu}_e$	electron anti-neutrino	$\bar{\nu}_\mu$	muon anti-neutrino	$\bar{\nu}_\tau$	tauon anti-neutrino
0	ν_e	electron neutrino	ν_μ	muon neutrino	ν_τ	tauon neutrino
-1/3	d	down	s	strange	b	bottom
-2/3	$\bar{\text{u}}$	anti-up	$\bar{\text{c}}$	anti-charm	$\bar{\text{t}}$	anti-top

Simple Composite Particles

particle	antiparticle	energy(MeV)
$\text{p} = \text{uud}$	$\bar{\text{p}} = \bar{\text{u}}\bar{\text{u}}\bar{\text{d}}$	938.272
$\text{n} = \text{udd}$	$\bar{\text{n}} = \bar{\text{u}}\bar{\text{d}}\bar{\text{d}}$	939.566
$\pi^+ = \text{u}\bar{\text{d}}$	$\pi^- = \bar{\text{u}}\text{d}$	139.568
$\text{e}^- = \bar{\text{u}}\text{d}\nu_e$	$\text{e}^+ = \text{u}\bar{\text{d}}\bar{\nu}_e$	0.511
$\mu^- = \bar{\text{u}}\text{d}\nu_\mu$	$\mu^+ = \text{u}\bar{\text{d}}\bar{\nu}_\mu$	105.658
$\tau^- = \bar{\text{u}}\text{d}\nu_\tau$	$\tau^+ = \text{u}\bar{\text{d}}\bar{\nu}_\tau$	1784.2

All the fundamental particles are conserved. All leptons contain a neutrino. Pions are bosons because the quark spins cancel. Fractional charges are probably one-dimensional and two-dimensional in some cellular automaton rules. Free particles can be only three-dimensional so free quarks cannot exist. Here is a sampling of weak interactions with braces indicating virtual pairs:

$$\text{n} \to \text{n} + \{\text{e}^+\text{e}^-\} = \text{udd} + \text{u}\bar{\text{d}}\bar{\nu}_e\bar{\text{u}}\text{d}\nu_e = \text{uud} + \bar{\text{u}}\text{d}\nu_e + \bar{\nu}_e = \text{p} + \text{e}^- + \bar{\nu}_e$$

$$\mu^+ \to \mu^+ + \{\text{e}^+\text{e}^-\} = \text{u}\bar{\text{d}}\bar{\nu}_\mu + \text{u}\bar{\text{d}}\bar{\nu}_e\bar{\text{u}}\text{d}\nu_e = \bar{\nu}_\mu + \text{e}^+ + \nu_e$$

$$\mu^- \to \mu^- + \{\text{e}^+\text{e}^-\} = \bar{\text{u}}\text{d}\nu_\mu + \text{u}\bar{\text{d}}\bar{\nu}_e\bar{\text{u}}\text{d}\nu_e = \nu_\mu + \text{e}^- + \bar{\nu}_e$$

$$\pi^+ \rightarrow \pi^+ + \{\mu^+\mu^-\} = \mathrm{u}\bar{\mathrm{d}} + \mathrm{u}\bar{\mathrm{d}}\bar{\nu}_\mu\bar{\mathrm{u}}\mathrm{d}\nu_\mu = \mu^+ + \nu_\mu$$

$$\pi^- \rightarrow \pi^- + \{\mu^+\mu^-\} = \bar{\mathrm{u}}\mathrm{d} + \mathrm{u}\bar{\mathrm{d}}\bar{\nu}_\mu\bar{\mathrm{u}}\mathrm{d}\nu_\mu = \mu^- + \bar{\nu}_\mu$$

$$\mu^- + \mathrm{p} \rightarrow \bar{\mathrm{u}}\mathrm{d}\nu_\mu + \mathrm{uud} = \nu_\mu + \mathrm{n}$$

$$\bar{\nu}_e + \mathrm{p} \rightarrow \bar{\nu}_e + \mathrm{p} + \{\mathrm{e}^+\mathrm{e}^-\} = \bar{\nu}_e + \mathrm{uud} + \mathrm{u}\bar{\mathrm{d}}\bar{\nu}_e\bar{\mathrm{u}}\mathrm{d}\nu_e = \mathrm{udd} + \mathrm{u}\bar{\mathrm{d}}\bar{\nu}_e = \mathrm{n} + \mathrm{e}^+$$

$$\begin{aligned} \mathrm{p} + \mathrm{p} \rightarrow \mathrm{p} + \mathrm{p} + \{\mathrm{e}^+\mathrm{e}^-\} &= \mathrm{uud} + \mathrm{uud} + \mathrm{u}\bar{\mathrm{d}}\bar{\nu}_e\bar{\mathrm{u}}\mathrm{d}\nu_e \\ &= \mathrm{uud} + \mathrm{udd} + \mathrm{u}\bar{\mathrm{d}}\bar{\nu}_e + \nu_e = \mathrm{pn} + \mathrm{e}^+ + \nu_e \end{aligned}$$

If the lepton structure is equal to a pion plus a neutrino, what determines the mass? Since mass is determined by internal motions produced by cellular automaton rules, we can make an analogy of sorts (a gedanken astrophysics analogy (Kurucz 1992)) to the internal structure of molecules expressed in partition functions. A proton or neutron consists of three charged quarks that interact and execute internal motions. Think of them as triatomic molecules that have huge partition functions because of all the modes of vibration. Think of a pion as a diatomic molecule with a deep potential well with many states but fewer states than the triatomic molecule so the mass of a pion is considerably less than that of a proton, $\pi/\mathrm{p} = 1/7$. Think of an electron as a diatomic molecule in which the electron neutrino somehow prevents the quarks from interacting more than one way. There is only one level in a potential well so the electron mass is small, $\mathrm{e}/\mathrm{p} = 1/1836$ and $\mathrm{e}/\pi = 1/280$. Since the quark motion is localized in a small volume, an electron is a small coulomb target. In the muon, the mu neutrino has some other rule that does not strongly block the quark interaction. The muon mass is reduced only slightly from that of a pion, $\mu/\pi = 3/4$ and $\mu/\mathrm{p} = 1/9$. In the tauon, the tauon neutrino must enhance the quark interaction, perhaps by keeping the quarks from moving far apart. It would act like a high barrier hump on the diatomic potential to produce more high-statistical-weight bound levels, so the tauon mass is much greater than the pion mass, $\tau/\pi = 13$, and even larger than the proton mass, $\tau/\mathrm{p} = 2$.

Since electrons are composite particles, they no longer present singularity or normalization problems. In low energy atomic physics electrons and nucleons have impenetrable substructure.

BLACK HOLES

Black holes are easy to explain without singularities. Adding mass to a neutron star causes the neutrons to collapse into boson di-neutrons with spins anti-parallel, $\mathrm{n} + \mathrm{n} = \mathrm{udd} + \mathrm{udd} \rightarrow \mathrm{uddudd} = \text{di-n}$. The neutron star becomes a di-neutron star. This can be a gradual transformation, not a catastrophe. If matter is added slowly, the neutron star becomes an invisible black hole and continues to grow until the fermion nature of the quarks limits the compression.

Continuing to add mass to a di-neutron star causes the quarks within the di-neutrons to pair with spins opposed so they become di-quark bosons with 0 spin, di-n = uddudd $\rightarrow$ uu-dd-dd = di-q-di-n. The di-neutron star becomes a di-quark-di-neutron star which is a super-massive black hole.

A cellular automaton has to have a density limit to prevent overloading the "computation" in a small volume. The simplest cutoff is to make gravity repulsive at high density to automatically blow apart dense concentrations. This could be built into the cellular rules for each particle.

ANTIMATTER

There is a missing anti-matter problem if this universe began in a Big Bang of radiation. Starting with radiation implies that all primordial particles were made by pair production as the universe cooled. If pair production does not dominate, then matter and antimatter do not have to balance.

The idea of a di-quark-di-neutron black hole suggests that our universe "started" from a collection of ultra-massive black holes (UMBHs) statistically uniformly distributed throughout the cellular automaton. For example, the initial state might be 10^{12} to 10^{13} 10^{13}-to-10^{14}-solar-mass black holes with average separation less than a megaparsec.

At the first tick the density in the ultra-massive black holes exceded the density cutoff so gravity was repulsive. The ultra-massive black holes expanded at sub-light speed. The di-quark-di-neutrons expanded and became di-neutrons. The di-neutrons expanded and became neutrons. The neutrons expanded and became protons and electrons and anti-electron-neutrinos, and deuterons, and alpha particles, etc. The initial number of neutrons was fixed. The proton number, the electron number, and the anti-electron-neutrino number are equal. Subsequent pair production does not affect the baryon (neutron+proton) total. There is no antimatter problem. The universe is fundamentally biased toward matter.

The statistical equilibrium and the formation of nuclei led to different abundances, including heavier nuclei, and different properties than we are used to from a Big Bang prediction.

The expanding material from each ultra-massive black hole collided with the material from its neighbors and formed a pattern of density perturbations at galaxy scale, at globular-cluster scale, and at massive-Population-III-star scale. The original locations of the ultra-massive black holes became regions of low density. The perturbations evolved into the universe as we know it, including the background radiation. I have described that evolution in my paper on radiatively-driven cosmology (Kurucz 2000). I will produce an updated version.

THE CELLULAR AUTOMATON UNIVERSE

The cellular automaton has a fixed number of cells, say a three-dimensional modular space cube with a large prime number K for the modulus. Time has the same modulus. If a plausible minimum time in particle physics is $\sim 10^{-28}$s, the cell size would be $\sim 3\times 10^{-18}$ cm, about 10000 cells in a classical electron radius. The cellular automaton is complete in itself. If the modulus is, say, twice the age of the oldest stars, 30 billion years, $K\sim 10^{46}$. The number of cells, the largest physical number, is $K^3 \sim 10^{138}$. Each cell appears to be the center of the universe.

Each type of particle has a set of rules that determine its motion. The occupation of each cell at each tick is determined by considering the occupation of that cell and all the cells neighboring in space and time. The definition of neighbor is a fundamental property of the cellular automaton. If the cellular grid is three dimensional, a cell can be defined to have 26 neighbors, or 124 neighbors, or in other patterns that are considered in the cellular rules that determine particle motion. It can have neighbors in the past and neighbors in the future (as a predictor-corrector). I suggest that the cellular automaton has coordinates Nx, Ny, Nz, and Nt and that a particle can move in 26 ways, dNx and dNy and dNz $=$ 0, ± 1, and dNt $= +1$. These coordinates are not the local x, y, z, and t coordinates of our experience in special relativity.

The rule for momentum might be that a particle keeps track of and updates target coordinates Tx, Ty, Tz and tries to move to its target. A particle would be a vector. Interactions with other particles modify the choice of neighbor and the target coordinates.

A particle keeps track of its own energy with a counter Ne that has the same range as the coordinates, $K\sim 10^{46}$. At each step it can trade energy, increase or decrease or no change, with particles that it can interact with. In general a particle loses energy through interactions when it travels over significant distances.

The actual position and energy of a particle are unknowable. They can change $\sim 10^{19}$ times per nanosecond. There is no way to measure absolute position or time or energy, Nx, Ny, Nz, Nt, Ne. Photons follow indeterminate, irreproducible paths. In special relativity photon paths are used to measure relative space and time. But in physical special relativity the paths are "fuzzy" so measurements of relative space and time are "fuzzy" as well. Special relativity is a mathematical approximation to the real "fuzzy" physics that makes the universe interesting.

Since integration over neighboring cells determines motion, and since the neighboring cells themselves also change at every tick, there is no time-reversal. Physics cannot be run in reverse.

Particles and anti-particles have the same gravity rule: move in the direction that increases overlap with other particles. Above the density cutoff particles move in the direction that decreases their overlap.

Paradoxes do not fare well in a finite cellular automaton. The solution to Olber's paradox is that the sky is dark because there is not enough light.

Particles eventually circumnavigate the universe. The cellular automaton described here could run forever unless it learns to modify itself.

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