Fundamental Constants and Conservation Laws

Heui-Seol Roh
BK21 Physics Research Division, Department of Physics, Sung Kyun Kwan University, Suwon 440-746, Republic of Korea
(February 1, 2008)

This work describes underlying features of the universe such as fundamental constants and cosmological parameters, conservation laws, baryon and lepton asymmetries, etc. in the context of local gauge theories for fundamental forces under the constraint of the flat universe. Conservation laws for fundamental forces are related to gauge theories for fundamental forces, their resulting fundamental constants are quantitatively analyzed, and their possible violations at different energy scales are proposed based on experimental evidences.

PACS numbers: 11.30.-j, 11.30.Er, 11.30.Fs

One of the major developments in modern physics is the understanding of fundamental constants and conservation laws for fundamental forces governing the universe. Although some of them are clear, there still exist some mysterious fundamental constants and conservation laws in nature, which make underlying principles of the universe be complicated. The origin of several fundamental forces hold commonly underlying principles such as conservation laws, whose details are discussed in references [1–5]. The mysteries of fundamental constants may be uncovered if their origins can be traced by linking fundamental forces to local gauge theories possessing symmetries. Quantum gauge theories for fundamental forces hold completely underlying principles such as special relativity, quantum mechanics, and gauge invariance, and fundamental constants such as the Planck constant (h) and the light velocity (c) come from underlying principles, quantum mechanics and special relativity. In this context, the other fundamental constants and cosmological constants encountered in physics are considered in depth with relations to conservation laws associated with fundamental forces as the consequence of gauge invariance: other challenging problems including the baryon asymmetry and lepton asymmetry may be systematically investigated as well. This paper thus intends to report brief summaries for fundamental constants and conservation laws, whose details are discussed in references [6,7]. The above references deal with substantial steps toward the unification of fundamental forces beyond Einstein's general relativity for gravitational interactions [1]. Glashow-Weinberg-Salam (GWS) model for weak interactions [12], quantum chromodynamics (QCD) for strong interactions [13], and grand unified theory (GUT) [14].

Quantum gravity (QG) is introduced as an SU(N) gauge theory with the Θ vacuum term, which suggests that a certain group G for gravitational interactions leads to a group SU(3)F × SU(3)C for weak and strong interactions through dynamical spontaneous symmetry breaking (DSSB) [15]; the group chain is G ⊃ SU(3)F × SU(3)C [16]. The Lagrangian density for QG [15] is given by

\[ \mathcal{L}_{QG} = -\frac{1}{2} Tr G_{\mu\nu} G^{\mu\nu} + \sum_{i=1}^{3} \bar{\psi}_i i\gamma^\mu D_\mu \psi_i + \frac{g_5^2}{16\pi^2} Tr G_{\mu\nu} G^{\mu\nu}, \]

where the bare Θ term [15] is a nonperturbative term added to the perturbative Lagrangian density with an SU(N) gauge invariance. The subscript i stands for the classes of pointlike spinor ψ and \( A_\mu = \sum_{a=0}^C A^a_\mu \lambda^a/2 \) stand for gauge fields. The field strength tensor is given by \( G_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu - ig_5 [A_\mu, A_\nu] \) and \( \tilde{G}_{\mu\nu} \) is the dual field strength tensor. The Θ term apparently odd under both P and T operation plays the role relating two different worlds, matter and vacuum. The forms of Lagrangian densities are commonly analogous for gravitational, weak, and strong interactions. Newton gravitation constant is defined as the effective coupling constant

\[ G_N/\sqrt{2} = g_f g_5^2/8M_G^2 \approx 10^{-38} \text{ GeV}^{-2} \]  (2)

with the gravitational coupling constant \( g_f \) and the gauge boson mass \( M_G \). The gauge boson mass \( M_G \) decreases through the condensation of the singlet graviton:

\[ M_G^2 = M_{Pl}^2 - g_f g_5^2 \langle \phi \rangle^2 = g_f g_5^2 |A_0 - \langle \phi \rangle|^2 \]  (3)

where \( A_0 \) is the singlet gauge boson with even parity and \( \langle \phi \rangle \) is the condensation of singlet gauge boson with odd parity. QCD as an SU(3)C gauge theory is the analogous dynamics of QWD as an SU(3)F gauge theory; QCD produces QND as an SU(2)_N × U(1)_Z gauge theory for nuclear interactions and then produces a U(1)_Y gauge theory for massless gauge boson (photon) dynamics just as QWD produces the GWS model as an SU(2)_L × U(1)_Y
gauge theory for weak interactions and then produces a $U(1)_c$ gauge theory for photon dynamics [3]. The constraint of the extremely flat universe $\Omega - 1 = -10^{-61}$, required by gauge theories [12,13] and inflation scenario [10] and confirmed by the experiments BUMERANG-98 and MAXIMA-1 [8], leads to

$$\Omega = (\langle \rho_m \rangle - \Theta \rho_m)/\rho_G = 1 - 10^{-61},$$

where $\rho_m$ is the matter energy density, $\langle \rho_m \rangle$ is the zero point energy density, and $\rho_G$ is the vacuum energy density. This means that the ratio of the zero point energy density to the vacuum energy density is $\langle \rho_m \rangle/\rho_G = 1$ and the $\Theta$ constant is obtained by

$$\Theta = 10^{-61} \rho_G/\rho_m.$$  

If the matter energy density in the universe $\rho_m \approx \rho_c \approx 10^{-47} \text{GeV}^4$ is conserved, the $\Theta$ constant depends on the gauge boson mass $M_G$ since $\rho_G = M_G^4/8\pi^2$: $\Theta = 10^{-61} M_G^4/\rho_c$. $-10^{-61}$ represents the $10^{30}$ expansion in one dimension, which is required by the inflation scenario [10]: $N_R = i/(\Omega - 1)^{1/2} \approx 10^{30}$. The value of $\Theta$ also makes the relation of the matter energy density $\rho_m$ to the effective cosmological constant $\Lambda$ connected with the effective cosmological constant defined by

$$\Lambda_c = \frac{8\pi G_N M_G^4}{\rho_G}$$

where $\Lambda_{Pl} \approx 10^{122} \rho_c = 10^{38} \text{GeV}^4$ at the Planck epoch, $\Lambda_{EW} \approx 10^{-30} \text{GeV}^2$ at the weak epoch, $\Lambda_{QCD} \approx 10^{-42} \text{GeV}^2$ at the strong epoch, and $\Lambda_0 = 3H_0^2 \approx 10^{-84} \text{GeV}^2$ at the present epoch. In matter mass generation of references [3,4], the difference number of even-odd parity singlet fermions $N_{sd}$ in intrinsic two-space dimensions suggests the a degenerated particle number $N_{sp}$ in the intrinsic radial coordinate and an intrinsic principal number $n_m$; these quantum numbers are connected by the relation $n_m = N_{sp} = N_{sd}$ and the Dirac quantization condition $\sqrt{\gamma_5 g_5 g_{5m}} = 2\pi N_{sp}$ is satisfied. The intrinsic principal quantum number $n_m$ consists of three quantum numbers, $n_m = (n_c, n_i, n_s)$ where $n_c, n_i$, and $n_s$ are color, isospin, spin intrinsic principal quantum numbers respectively: total intrinsic angular momentum is the vector sum of spin, isospin, and color spin, $\vec{J}_f = \vec{S} + \vec{I} + \vec{C}$. In this approach [4,10], vacuum energy and matter energy are spatially quantized as well as photon energy and phonon energy. The vacuum represented by massive gauge bosons is quantized by the maximum wavevector mode

$$N_R = i/(\Omega - 1)^{1/2} \approx 10^{30}$$

and the total gauge boson number $N_G = 4\pi N_{Pl}^3/3 \approx 10^{91}$. The maximum wavevector mode $N_R \approx 10^{30}$ is manifest since the universe size is $R_{Pl} \approx 10^{-3} \text{cm}$ at the Planck scale $l_{Pl} \approx 10^{-33} \text{cm}$ and the universe size is $R_0 \approx 10^{28} \text{cm}$ at the present scale $l_{Pl} \approx 10^{-3} \text{cm}$ in the extremely flat universe, $\Omega - 1 = -10^{-61}$. Baryon matter represented by massive baryons is quantized by the maximum wavevector mode (Fermi mode) $N_F \approx 10^{26}$ and the total baryon number $B = N_B = 4\pi N_F^2/3 \approx 10^{78}$. This is the result of the conservation of the baryon number. Baryon matter quantization is consistent with the nuclear matter number density

$$n_n = n_B = A/(4\pi^3/3) \approx 1.95 \times 10^{38} \text{cm}^{-3} (8)$$
given by the nuclear mass number $A = B$ and the nuclear matter radius $r = r_0 A^{1/3}$ and with Avogadro’s number $N_A = 6.02 \times 10^{23} \text{mol}^{-1} \approx 10^{49} \text{cm}^{-3}$ in the matter. The baryon number density at the nuclear interaction scale $10^{-1} \text{GeV}$ is $10^{26} \text{cm}^{-3}$ in the universe size $R_{QCD} \approx 10^{17} \text{cm}$, whose volume $10^{61} \text{cm}^3$ is $10^{12}$ times bigger than the matter volume $10^{39} \text{cm}^3$. Electrons with the mass 0.5 MeV might be similarly quantized by $N_F \approx 10^{26}$ and the total number $10^{30}$ if the electron number is conserved as the result of the electron number conservation under the assumption of $\Omega_e = \rho_e/\rho_c \approx 1$. The maximum wavevector mode $N_F$ is close to $10^{30}$ if the mass quantization unit of fermions $10^{-12} \text{GeV}$ (the baryon number $B \approx 10^{-12}$) is used rather than the mass baryons 0.94 GeV ($B = 1$) under the assumption of the fermion number conservation. Massless photons are quantized by the maximum wavevector mode $N_\gamma \approx 10^{29}$ and the total photon number $N_{\gamma} \approx 4\pi N_{Pl}^2/3 \approx 10^{88}$. Cosmic microwave background radiation (CMBR) is the conclusive evidence for massless gauge bosons (photons) with the total number $N_{\gamma} \approx 10^{88}$. Massless phonons in the matter space are quantized by the maximum wavevector mode (Debye mode) $N_D \approx 10^{26}$ and the total phonon number $N_{\phi} \approx 4\pi N_{Pl}^2/3 \approx 10^{75}$. Total particle numbers such as the gauge boson number $N_G \approx 10^{91}$, the baryon number $N_B \approx 10^{78}$, the electron number $N_e \approx 10^{81}$, the photon number $N_{\gamma} \approx 10^{88}$, and the phonon number $N_{\phi} \approx 10^{75}$ are conserved good quantum numbers as described above. The matter current at the Planck scale, the $(V - A)$ current and the electromagnetic current at the electroweak scale, the baryon current and the proton current at the strong scale, and the lepton current at the present scale might be conserved currents at different energy scales. The proton number conservation is the consequence of the $U(1)_c$ gauge theory just as the electron number conservation is the consequence of the $U(1)_e$ gauge theory. In gravitational interactions, the predicted typical lifetime for a particle with the mass 1 GeV is $\tau_\mu = 1/\Gamma_\mu \approx 1/G_N m_\mu \approx 10^{50}$ years using the analogy of the lifetime of the muon $\tau_\mu = 192\pi^3/G_N m_\mu^5$ in weak interactions. Therefore, in the proton decay $p \rightarrow \pi^0 + e^+$ at the energy $E \ll M_{Pl}$, the proton would have much longer lifetime than $10^{42}$.
years predicted by GUT [14] if the decay process is gravitational. In fact, the lower bound for the proton lifetime is $10^{32}$ years at the moment. If the electric charge is completely conserved, the electron can not decay. The present lower bounds for the electron lifetime are bigger than $10^{21}$ years for the electron decay into neutral particles and $10^{25}$ years for the decay $e^- \rightarrow \gamma + \nu_e$ [17]. The baryon number conservation is the result of the $U(1)_Z$ gauge theory for strong interactions just as the lepton number conservation is the result of the $U(1)_Y$ gauge theory for weak interactions. The bound of the lepton number nonconservation process is expressed by the branching ratio $B(K^+ \rightarrow \pi^- e^+ e^-) < 10^{-8}$ or $B(\mu^- \rightarrow e^+ N') < 7 \times 10^{-11}$ and the bound of lepton flavor violation is shown by $B(\mu^- \rightarrow e^- \gamma) < 5 \times 10^{-11}$, $B(\mu^- \rightarrow e^- \gamma) < 7 \times 10^{-11}$, or $B(\mu^- \rightarrow 3e^-) < 10^{-13}$. Table I shows relations between conservation laws and gauge theories in strong and weak interactions. Conservation laws of the baryon number, lepton number, and electric charge number are good in weak, strong, and gravitational interactions. The breaking of discrete symmetries through the condensation of singlet gauge bosons causes various asymmetries at different scales: the matter-antimatter asymmetry with $\Theta_{PL} \approx 10^6$ at the Planck scale, the lepton-antilepton asymmetry with $\Theta_{EW} \approx 10^{-4}$ at the weak scale, and the baryon-antibaryon asymmetry with $\Theta_{QCD} \approx 10^{-12}$ at the strong scale. The absence of the right-handed neutrino shows P violation [15] and the decay of the neutral kaon [19] and the electric dipole moment of electrons [20] show CP violation by intermediate vector bosons. Pseudoscalar and vector mesons are observable while their parity partners, scalar and pseudovector mesons, are not observable because of massive gluons: the absence of the $U(1)_A$ particle is due to the nonconservation of the color axial vector current. Similarly, there are no baryon octet and decuplet parity partners. The evidence of CP and T violation appears in the electric dipole moment of the neutron [3]. The conservation of the fermion number $N_f \approx 10^{21}$ in the unit of mass $10^{-12} \text{GeV}$ is good at the Planck scale under the assumption with no supersymmetry and higher dimensions. Features of conservation laws for fundamental forces are summarized in Table I.

The baryon asymmetry due to gravity is at present very weak by the effective coupling constant $G_N \approx 10^{-38} \text{GeV}^{-2}$. In terms of the baryon energy density $\rho_B \approx 1.88 \times 10^{-29} \Omega_B h_0^2 \text{ g cm}^{-3}$, the number of protons per unit volume is $n_B = \rho_B/m_p \approx 1.13 \times 10^{-5} \Omega_B h_0^2 \text{ cm}^{-3}$. The baryon-antibaryon asymmetry at present is estimated by the number of baryons dominating over the number of antibaryon by a tiny factor of $10^{-10}$ if $\Omega_B \approx 0.1$:

$$\delta_B = \frac{N_B - N_B}{N_B + N_B} = \frac{N_B}{N_{\gamma}} \approx \frac{10^{78}}{10^{68}} = 10^{-10} \tag{9}$$

where $N_{\gamma}$ is the total number of massless gauge bosons (photons). The lepton-antilepton asymmetry, which implies the lepton number violation observable at present, is an analogue of the baryon asymmetry: $\delta_L = \frac{N_L - N_L}{N_L + N_L} = \frac{N_L}{N_{\gamma}}$ with the total lepton number $N_L = L$. It consist of the electron asymmetry

$$\delta_e = \frac{N_e - N_e}{N_{\gamma}} \approx \frac{10^{81}}{10^{68}} = 10^{-7} \tag{10}$$

and the neutrino asymmetry $\delta_\nu = \frac{N_\nu - N_\nu}{N_{\gamma}} \approx \frac{10^{99}}{10^{68}} = 10^3$ according to the electron mass $0.5 \text{ MeV}$ and the probable neutrino mass around $10^{-3} \text{ eV}$ under the assumption of $\Omega_e = \rho_e/\rho = 1$. The neutrino asymmetry is $\delta_\nu = N_\nu/N_{\gamma} \approx 10^{-8} / 10^{68} = 1$ if the neutrino mass $m_\nu \approx 1 \text{ eV}$. Lepton asymmetries of muon and tau $\delta_\mu = N_\mu/N_{\gamma} \approx 10^{79} / 10^{68} = 10^{-9}$ and $\delta_\tau = N_\tau/N_{\gamma} \approx 10^{78} / 10^{88} = 10^{-10}$ are as well expected if lepton matter has the same order with the critical density $\rho_c$. The baryogenesis and leptogenesis described above can be discussed from the gauge theory point of view. Massive gravitons might violate discrete symmetries and the antimatter (or antibaryon or antilepton) number conservation just as the Higgs mechanism in electroweak interactions violates discrete symmetries and chiral symmetry. The discrete symmetries of P, C, CP, and T are explicitly broken during DSSB as the requirement of the baryon asymmetry. If the antimatter number current is not conserved, some antimatter particle spectra must disappear. Since the interaction rate is given by $T \sim n\sigma v \sim G_N^2 T^5$ and the expansion rate is given by $H_e \sim T^2 / M_{Pl}$, the ratio of the interaction rate to the expansion rate becomes $\Gamma / H_e \sim T^3 / M_{Pl}^2$, which indicates nonequilibrium starts at the temperature $T \sim M_{Pl}$. The population of gravitons and the number of antimatter were suppressed by the Boltzmann factor $\exp(-M_{Pl}/T)$ since $T < M_{Pl}$. Baryon and lepton asymmetries predicted under the assumption of $\Omega_B = \rho_B / \rho_c \approx 1$ and $\Omega_L = \rho_L / \rho_c \approx 1$ seem to indicate the nonconservation of the lepton and baryon quantum numbers separately above the weak scale since $\delta_L \neq \delta_B$. The baryon number is conserved below the strong scale as illustrated by the $U(1)_Z$ gauge theory and the lepton number is conserved below the weak scale as illustrated by the $U(1)_Y$ gauge theory but they may not be separately conserved and only the $(B - L)$ quantum numbers may be conserved above the weak scale. In the
minimal GUT of the $SU(5)$ gauge theory [14], the matter asymmetry term involved in perturbation theory is too small to explain the observed baryon asymmetry. However, nonperturbative processes during DSSB by QG as a gauge theory indicates that the asymmetries are carried by the current anomaly and the gauge boson condensation.

Table 11 summarizes fundamental and cosmological constants in quantum cosmology [7]: the gauge boson mass $M_G$, the effective coupling constant $G_G \approx \sqrt{2} g^2 / 8 M_2$, the gauge boson number density $n_G \approx M_2^2$, the vacuum energy density $V_c(\bar{\phi}) \approx M_2^4$, the cosmological constant $\Lambda_e \approx 8 \pi G N M_2^4$, the Hubble constant $H_e = (\Lambda_e/3)^{1/2} \approx (8 \pi G N M_2^4/3)^{1/2}$, the baryon number density $n_B$, the baryon mass density $\rho_B$, the electron number density $n_e$, the electron mass density $\rho_e$, the photon energy $E_{\gamma}$, the photon number density $n_{\gamma}$, the phonon energy $\epsilon_{\nu}$, the phonon number density $n_{\nu}$, the Hubble constant $H \approx 10^{-61} \rho_e / \rho_m$, and the intrinsic topological constant $\nu \approx \rho_m / \rho_G$. The values of the baryon (electron) number density and mass density represent ones when the vacuum volume is used while the values within parentheses represent ones when only the baryon (electron) matter volume is used.

New noble concepts based on local gauge theories for fundamental forces are introduced under the constraint of the flat universe, which is required by quantum gauge theories and is confirmed by the recent experiments BUMERANG-98 and MAXIMA-1. Intrinsic quantum numbers emerge in analogy with extrinsic quantum numbers. Fundamental constants and cosmological parameters are qualitatively and quantitatively discussed as the consequences of gauge invariance for fundamental forces, which lead to conservation laws. The proton number conservation is the consequence of the $U(1)_f$ gauge theory just as the electron number conservation is the consequence of the $U(1)_e$, gauge theory and the baryon number conservation is the result of the $U(1)_Z$ gauge theory for strong interactions just as the lepton number conservation is the result of the $U(1)_Y$ gauge theory for weak interactions. However, there is possibility not for the separate conservation of the baryon number or the lepton number but for the combined conservation of the $(B - L)$ number conservation in the energy regions above $10^2$ GeV. Discrete symmetries $\mathbf{C}, \mathbf{P}, \mathbf{T}, \text{and CP are nonperturbatively violated during DSSB although they are not perturbatively violated.}$ The apparent baryon asymmetry indicates the nonperturbative violation from the gauge theory point of view for gravitation and the possible lepton asymmetry emerges in analogy with the baryon asymmetry. Experimental precision tests such as the proton decay, lepton flavor violation, electric charge violation, etc. as well as nonperturbative discrete symmetry violation are demanded at higher and lower energies. This work may thus significantly contribute to the understanding of profound underlying principles and the unification of fundamental forces since fundamental constants and conservation laws are remarkably clarified.

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TABLE I. Relations between Conservation Laws and Gauge Theories

| Force  | Conservation Law | Gauge Theory |
|--------|------------------|--------------|
| Electromagnetic | Proton | $U(1)_f$ |
| Strong | Baryon | $U(1)_Z$ |
| Strong | Color Vector | $SU(2)_N \times U(1)_Z$ |
| Strong | Color | $SU(3)_C$ |
| Electromagnetic | Electron | $U(1)_e$ |
| Weak | Lepton | $U(1)_Y$ |
| Weak | V-A | $SU(2)_L \times U(1)_Y$ |
| Weak | Isotope (Isospin) | $SU(3)_I$ |

TABLE II. Overview of Conservation Laws

| Conservation | Gravity | Electromagnetic | Weak | Strong |
|--------------|---------|-----------------|------|--------|
| Energy, Momentum, Angular Momentum | yes | yes | yes | yes |
| Charge, Baryon, Lepton | no | yes | yes | yes |
| P, C, T, CP | no | yes | no | no |
| TCP | yes | yes | yes | yes |

TABLE III. Fundamental and Cosmological Constants in Quantum Cosmology

| Constant | Gravity | Weak | Strong | Present |
|----------|---------|------|--------|---------|
| Gauge Boson Mass $M_G$ (GeV) | $10^{19}$ | $10^2$ | $10^{-1}$ | $10^{-12}$ |
| Effective Coupling Constant $G_G$ (GeV$^{-2}$) | $10^{-38}$ | $10^{-5}$ | $10^{-1}$ | $10^{24}$ |
| Gauge Boson Number Density $n_G$ (cm$^{-3}$) | $10^{98}$ | $10^{37}$ | $10^{39}$ | $10^9$ |
| Vacuum Energy Density $\epsilon_V$ (g cm$^{-3}$) | $10^{10}$ | $10^{25}$ | $10^{14}$ | $10^{-29}$ |
| Cosmological Constant $\Lambda$ (GeV$^2$) | $10^{48}$ | $10^{-30}$ | $10^{-42}$ | $10^{-84}$ |
| Hubble Constant $H_e$ (GeV) | $10^{19}$ | $10^{-15}$ | $10^{-21}$ | $10^{-42}$ |
| Baryon Number Density $n_B$ (cm$^{-3}$) | $10^{26}$ ($10^{38}$) | $10^{-6}$ ($10^4$) |
| Baryon Mass Density $\rho_B$ (g cm$^{-3}$) | $10^5 (10^{14})$ | $10^{-31} (10^{-20})$ |
| Electron Number Density $n_e$ (cm$^{-3}$) | $10^{48} (10^{10})$ | $10^{-41} (10^{-11})$ | $10^{-3} (10^1)$ |
| Electron Mass Density $\rho_e$ (g cm$^{-3}$) | $10^{-23} (10^{94})$ | $10^{-47} (10^{-74})$ | $10^{-31} (10^{-29})$ |
| Photon Energy $E_\gamma$ (GeV) | $10^{18}$ | $10^4$ | $10^{-2}$ | $10^{-13}$ |
| Photon Number Density $n_{\gamma}$ (cm$^{-3}$) | $10^{26}$ | $10^{24}$ | $10^{36}$ | $10^2$ |
| Photon Energy Density $\epsilon_\gamma$ (g cm$^{-3}$) | $10^{59}$ | $10^{24}$ | $10^{10}$ | $10^{-34}$ |
| Phonon Number Density $n_{\phi}$ (cm$^{-3}$) | $10^{24}$ | $10^{-2}$ | $10^{-10}$ |
| Phonon Energy Density $\epsilon_\phi$ (g cm$^{-3}$) | $10^{51}$ | $10^{-3}$ | $10^{-12}$ | $10^{-61}$ |
| Constant $\Theta$ | $10^{14}$ | $10^{-4}$ | $10^{-2}$ | $10^{-13}$ |
| Topological Constant $\nu$ | $10^{-122}$ | $10^{-91}$ | $10^{-49}$ | $10^0$ |