Basic Principles and Laws of Nature's Four Fundamental Forces/Interactions

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I. Four fundamental forces/interactions

II. Unified Field Theory
I. Four Fundamental Forces/Interactions

Physical laws of nature are based on a few simple and universal first first principles, and are often described by equations.
Gravity

- Galilei, Newton: \( F = -m \nabla \phi(r) = -\frac{GMm}{r^2} \), \( \phi(r) = -\frac{GM}{r} \)

- Einstein: \( R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = -\frac{8\pi G}{c^4}T_{\mu\nu} \)

- Ma-Wang, 2012:

\[
R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = -\frac{8\pi G}{c^4}T_{\mu\nu} - \nabla_\mu \Phi_\nu
\]

\[
F = -m \nabla g_{00} = -mMG \left[ \frac{1}{r^2} + \frac{k_0}{r} - k_1r \right],
\]

where \( k_0 = 4 \times 10^{-18} km^{-1}, \ k_1 = 10^{-57} km^{-3}. \) Gravity can display both attractive and repulsive behaviors, and the new gravitational field equations give rise to a new unified theory for dark energy and dark matter.
Strong interaction

- Quantum Chromodynamics based on an $SU(3)$ gauge theory (Yukawa, Yang-Mills, Gell-Mann, O. Greenberg, ...)

- Layered strong interactions potentials (Ma-Wang, 2012 & 13): based on two new principles: principle of interaction dynamics (PID), and principle of representation invariance (PRI):

$$S_0 = g_s(\rho) \left[ \frac{1}{r} - \frac{A_s}{\rho} \left( 1 + \frac{r}{R} \right) e^{-r/R} \right], \quad g_s(\rho) = g_s \left( \frac{\rho_w}{\rho} \right)^3,$$

where $A_s$ is a constant depending on the particle type, and $R$ is the attracting radius of strong interactions given by

$$R = \begin{cases} 
10^{-16}\text{cm} & \text{for } w^* \text{ and quarks}, \\
10^{-13}\text{cm} & \text{for hadrons.}
\end{cases}$$
These potentials match very well with experimental data.

Again, strong interaction demonstrates both attraction and repelling behaviors.
**Quark confinement:** With these potentials, the binding energy of quarks can be estimated as

\[
E_q \sim \left(\frac{\rho_n}{\rho_0}\right)^6 E_n \sim 10^{24} E_n \sim 10^{22}\text{GeV},
\]

where \(E_n \sim 10^{-2}\text{GeV}\) is the binding energy of nucleons.

This clearly explains the quark confinement.
Short-range nature of strong interaction:

With the strong interaction potentials, at the atom/molecule scales, the ratio between strong force and electromagnetic attraction force is

\[
\frac{F_a}{F_e} = 9g_s^2 \left(\frac{\rho_0}{\rho_a}\right)^6 / e^2 \sim \begin{cases} 10^{-38} & \text{at the atomic level,} \\
10^{-44} & \text{at the molecular level.} \end{cases}
\]

This demonstrates the short-range nature of strong interaction.
Weak interactions

• An $SU(2)$ gauge theory

• Ma-Wang, 2012 & 2013: Layered gauge weak interaction potentials:

$$W_0 = g_w(\rho)e^{-r/r_0}\left[\frac{1}{r} - \frac{A_w}{\rho} \left(1 + \frac{2r}{r_0}\right)e^{-r/r_0}\right], \quad g_w(\rho) = g_w\left(\frac{\rho_w}{\rho}\right)^3$$

where $\rho_w$ and $\rho$ are the radii of the constituent weakton and the particle, $A_w$ is a constant depending on the types of particles, and $r_0 \approx 10^{-16}\text{ cm}$ is the radius of weak interaction.

• The potentials show that the weak interaction is also short-ranged

• The weak interaction/force demonstrates both attraction and repelling behaviors.
Stability of matters

The attraction and repelling nature of all four forces leads to the stability of the matter in the universe.
II. Unified Field Theory

The unified field model is determined by the following first principles:

- principles of general relativity and Lorentz invariance, postulated by Einstein (1905, 1915)


- principle of interaction dynamics (PID), postulated by Ma-Wang, 2012

- principle of representation invariance (PRI), postulated by Ma-Wang, 2012
Unified field model (Ma-Wang, 2012):

\[ R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \frac{8\pi G}{c^4}T_{\mu\nu} = \left[ \nabla_\mu - \frac{e\alpha^E}{\hbar c}A_\mu - \frac{g_w\alpha^w_a}{\hbar c}W^a_\mu - \frac{g_s\alpha^s_k}{\hbar c}S^k_\mu \right] \Phi_\nu, \]

\[ \partial^\nu F_{\nu\mu} - e\bar{\psi}\gamma_\mu\psi = \left[ \nabla_\mu - \frac{e\alpha^E}{\hbar c}A_\mu - \frac{g_w\alpha^w_a}{\hbar c}W^a_\mu - \frac{g_s\alpha^s_k}{\hbar c}S^k_\mu \right] \phi^E, \]

\[ G^{aw}_{ab} \left[ \partial^\nu W^b_{\nu\mu} - \frac{g_w}{\hbar c}\lambda^b_{cd}\alpha^{\alpha\beta}W^c_{\alpha\mu}W^d_{\beta} \right] - g_w \bar{L}\gamma_\mu\sigma_aL \]

\[ = \left[ \nabla_\mu + \frac{1}{4} \left( \frac{m_Hc}{\hbar} \right)^2 \right] x_\mu - \frac{e\alpha^E}{\hbar c}A_\mu - \frac{g_w\alpha^w_b}{\hbar c}W^b_\mu - \frac{g_s\alpha^s_k}{\hbar c}S^k_\mu \right] \phi^w, \]

\[ G^{sk}_{kj} \left[ \partial^\nu S^j_{\nu\mu} - \frac{g_s}{\hbar c}\Lambda^j_{cd}\alpha^{\alpha\beta}S^c_{\alpha\mu}S^d_{\beta} \right] - g_s \bar{q}\gamma_\mu\tau_kq \]

\[ = \left[ \nabla_\mu + \frac{1}{4} \left( \frac{m_\pi c}{\hbar} \right)^2 \right] x_\mu - \frac{e\alpha^E}{\hbar c}A_\mu - \frac{g_w\alpha^w_a}{\hbar c}W^a_\mu - \frac{g_s\alpha^s_j}{\hbar c}S^j_\mu \right] \phi^s, \]

\[ (i\gamma^\mu \tilde{D}_\mu - \tilde{m})\Psi = 0. \]