Chrial and Parity Symmetry

- The laws of nature are expected to remain the same under mirror reflection P (changing left to right) and with charge conjugation C (changing particles into antiparticles).

- Parity symmetry is known to be respected by classical gravitation, electromagnetism, and the strong interaction.

Parity, Chiral, and CP Violation In Weak Interaction

- The weak interaction acts only on left-handed particles and right-handed antiparticles. It has the maximal violation of parity.

- CP violation: CP symmetry could also be broken for weak interaction in limited circumstances.

Questions to Be Answered

Why weak interaction violates chiral, parity, and CP symmetry?

Why Do Electromagnetic and strong interaction Preserve Them?

Can String Theory Explain Them?

- String theory is a promising candidate for the grand unification theory.

- Integrate quantum theory and general relativity in a mathematically consistent way.

- String theory has the potential to predict the dimension of space-time, the particle and interaction spectrum, and to unify all the forces and fundamental particles.

Universal Wave Function Formulation of String Theory (UWFOST)

Uncertainty relation between space $\Delta\sigma$ and time $\Delta\tau$

$$\Delta\sigma\,\Delta\tau \geq l_p\, t_p$$

$$\Downarrow$$

$$\psi(L,T) = \exp(i \int_0^T d\tau \int_0^L d\sigma / l_p t_p)\, \psi(0,0)$$

- **Dark Energy and Dark Matter**
- **Prediction of Cosmological Constant**
- **Derive inflation scheme and inflaton**
- **Explain large structure of the universe**
- **Explain large-scale anisotropies & anomalous alignments in the microwave background.**

Basics of String Theory

Particle Physics → **String Theory**

$$A_1 = a\int d\tau \quad \Rightarrow \quad A_2 = \alpha\int d\tau\, d\sigma$$

Introducing fermionic coordinate θ,

$\theta^2 = \bar{\theta}^2 = \{\theta\ \bar{\theta}\} = 0$ → Super space

$$A_2 = \alpha\int d\tau\, d\sigma\, d\theta_\tau\, d\theta_\sigma$$

$$A_2 = \alpha\int dz\, d\bar{z}\, d\theta\, d\bar{\theta} = \alpha\int d^2z\, d^2\theta$$

$z = \sigma + i\tau$, $\bar{z} = \sigma - i\tau$,

$\theta = \theta_\sigma + i\theta_\tau$, $\bar{\theta} = \theta_\sigma - i\theta_\tau$,

Observed Spacetime and Internal Spacetime

The observed space–time X^M is a projection from the string (internal) space–time

$$X^M(\sigma, \tau, \theta_\tau, \theta_\sigma) = X^M(z,\bar{z}) + \theta\, \psi^M(z) + \bar{\theta}\ \tilde{\psi}^M(\bar{z}) + \theta\bar{\theta}\, F^M$$

$$A_2 = \alpha \int d^2z\ [\ \partial_z X^M \partial_{\bar{z}} X_M + \psi^M \partial_{\bar{z}} \psi_M + \tilde{\psi}^M \partial_z \tilde{\psi}_M\ ]$$

Conformal symmetry suggests that there exist two separate and independent sectors:

$[X^M(z), \psi^M(z)]$ and $[X^M(\bar{z}), \tilde{\psi}^M(\bar{z})]$

Here M is related to the coordinate and dimension in the observed space–time.

String Theory in Background Field

With background field $G_{\mu\nu}$ and $B_{\mu\nu}$,

$A_2 = \alpha \int d^2z[(G_{MN} + B_{MN})\, \partial_z X^M \partial_{\bar{z}} X^N + G_{MN}$ $(\psi^M D_{\bar{z}} \psi^N + \tilde{\psi}^M D_z \tilde{\psi}^N) + \frac{1}{2} R_{MN\rho\sigma}(X)\psi^M\psi^N \tilde{\psi}^\rho \tilde{\psi}$

$$D_{\bar{z}} \psi^N = \partial_{\bar{z}} \psi^N + [\, \Gamma^N{}_{\rho\sigma}(X) + \frac{1}{2} H^N{}_{\rho\sigma}(X)\,]\, \partial_{\bar{z}} X^\rho \psi^\sigma$$

$$D_z \tilde{\psi}^N = \partial_z \tilde{\psi}^N + [\, \Gamma^N{}_{\rho\sigma}(X) - \frac{1}{2} H^N{}_{\rho\sigma}(X)\,]\, \partial_z X^\rho \tilde{\psi}^\sigma$$

Compactification of extra dimension give rise to gauge interaction

String Model With Weak Interaction C, P, and CP Violation

Assumption: Our universe stays in one of the two separate and independent (left moving or left rotating, z or $\bar{\mathbf{z}}$) sectors

Result: If antimatter stays in the other sector or moving in the opposite direction, we may not be able to observe the antimatter although it exists.

Matter–Antimatter Asymmetry In Our Universe

String Model That Has Inherent Matter-AntiMatter Asymmetry

Consider two sets of Majorana-Weyl fermions $\psi_1{}^M$ and $\psi_2{}^M$

$$\Psi'^M(\bar{z}) = \psi_1{}^M(z)\, e_\sigma + \psi_2{}^M(z)\, e_\tau$$
$$= \tfrac{1}{2}\,(\psi_1{}^M(z) - i\psi_2{}^M(z)\, e_z + \tfrac{1}{2}\,(\psi_1{}^M(z) + i\psi_2{}^M(z))\; e_{\bar{z}}$$
$$= \psi^M(z) + \bar{\psi}^M(z)$$

$$\psi^M = \tfrac{1}{2}\,(\psi_1{}^M(z) + i\psi_2{}^M(z))\, e_z$$

$$\bar{\psi}^M = \tfrac{1}{2}\,(\psi_1{}^M(z) + i\psi_2{}^M(z))\; e_{\bar{z}}$$

$$A = \psi_1{}^M \partial_{\bar{z}}\psi_1{}^M + \psi_2{}^M(z)\partial_{\bar{z}}\psi_2{}^M$$

Action: $A = \bar{\psi}^M \partial_{\bar{z}} \psi^M$

Assumption

The observed spacetime M = 1, 2 corresponds to the internal spacetime (σ, τ), the weak interaction is connected with the SU(2) symmetry in the this two dimensional spacetime.

Why Weak Interaction Only Interact With Left Handed Particles and Right Handed Anti-particles?

We can see that in these two dimensions, the parity of the fermions is left-handed. This is because

$\psi^M = ½ (\psi_1^M (z) + i\psi_2^M (z))\ e_{\bar{z}}$

Momentum P is in the direction z, but particle is in the direction $e_{\bar{z}}$.

The parity of anti-particle is right handed. This is due to

$\bar{\psi}^M = ½ (\psi_1^M(z) + i\psi_2^M(z))\ e_z$

Momentum P is in the direction z, but fermion is in the direction $e_{\bar{z}}$.

Why Electromagnetic and Strong Interaction Can Interact With Both Left Handed and Right Handed Particles and Anti-particles?

Electromagnetic and strong gauge interaction comes from the compactification of other dimension. In other dimensions, the particle and anti-particle does not have such restrictions. Therefore, the electromagnetic and strong gauge interaction can interact with both left-handed particles and right-handed particles.

Why all Particles Have Flavor?

All particles in the standard model have flavor, but not every particle has electromagnetic or strong charge.

Because weak interaction is related to the internal space-time.

Summary of The String Model

- Can Explain Matter and Anti-matter asymmetry
- Why weak interaction can only interact with left-handed particles and right handed anti-particles
- Why all particles have flavor
- Why other gauge interaction can interact with both right-handed and left-handed particles and anti-particles

Assumption made in this model

1. Our universe stays in one of the two separate and independent (left moving or left rotating, z or $\bar{\mathbf{z}}$) sectors.

1. The observed spacetime M = 1, 2 corresponds to the internal spacetime (σ, τ), the weak interaction is connected with the SU(2) symmetry in the this two dimensional spacetime.

Conclusion

This model is worth further investigation.

- May have cosmological consequences
- May give a way to derive the Higgs boson mechanism
- May explain the hierarchy problems in physics