B-L as a Gauged Peccei-Quinn symmetry

@ Cargese (July 11th, 2018)

Motoo Suzuki

Institute for Cosmic Ray Research
(ICRR)
The University of Tokyo

arXiv : 1805.10029 and

Phys. Lett. B771, 327 (2017) , arXiv:1703.01112

In collaboration with Hajime Fukuda, Masahiro Ibe and Tsutomu. T. Yanagida

Strong CP problem

One of the long-standing problem in the Standard Model

QCD has its own P and CP-violating parameter: θ

$$\mathcal{L}_\theta \sim \frac{g^2}{32\pi^2}\bar{\theta} G\tilde{G}$$

θ parameter is observable

Neutron electric dipole moment constrains the θ

$$\bar{\theta} < 10^{-10}$$

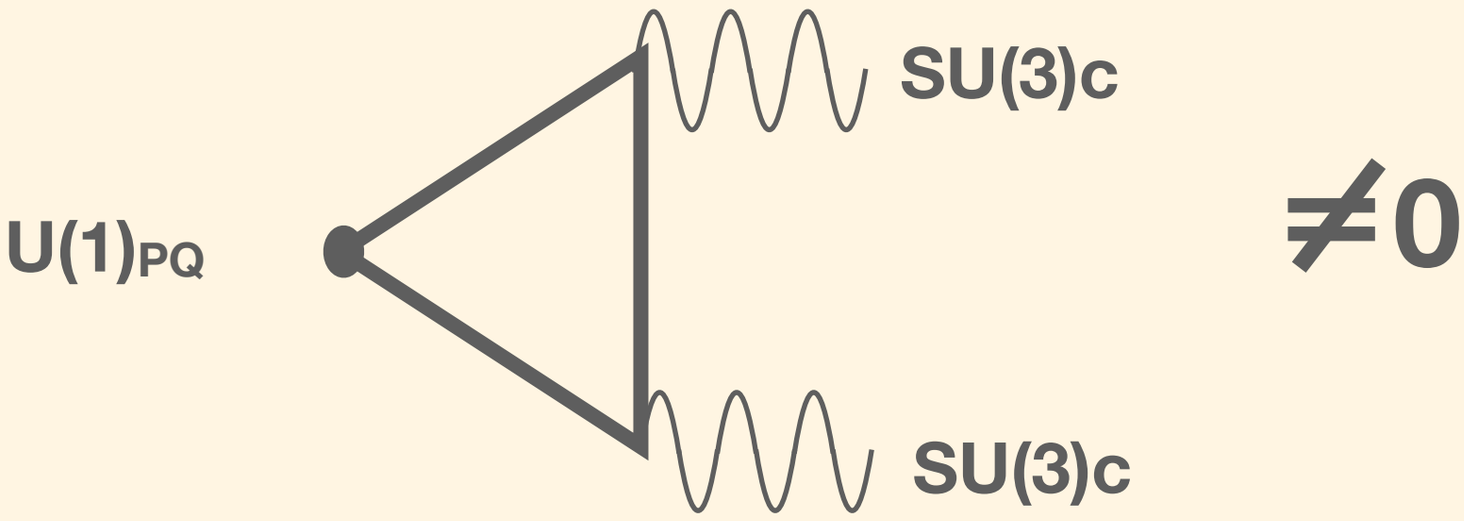
’06 Baker et al.

Why is the theta value so small ??

Peccei-Quinn mechanism

QCD anomalous symmetry: Peccei-Quinn (PQ) symmetry

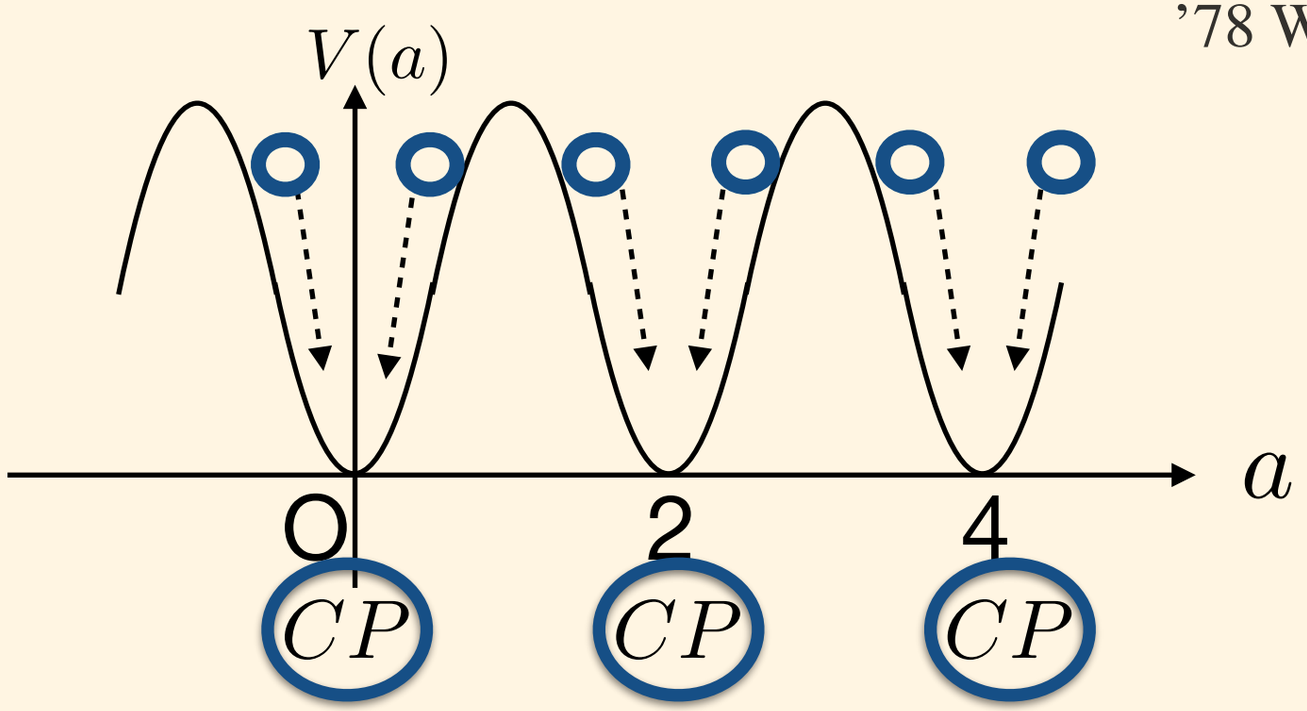
’77 Peccei and Quinn



$\neq 0$

Axion (U(1)PQ NG boson) dynamically cancel theta-term

’78 Weinberg, ’78 Wilczek



Peccei-Quinn mechanism can solve the Strong CP problem !!

Gravity badly and explicitly breaks PQ symmetry

Spontaneous PQ breaking scalar field (Global PQ charge : +1)

$$\Phi \ni \frac{1}{\sqrt{2}} f_{PQ} e^{i\frac{a}{f_a}}$$

a ***: axion***

If physics at Planck scale breaks PQ symmetry

$$\mathcal{L} \ni \frac{\Phi^5}{M_{\rm pl}} + h.c....$$

which distorts axion potential

$$V(a) \sim -m_a^2 f_a^2 \cos\left(\frac{a}{f_a}\right) + \left(\lambda_1 \frac{f_a^5}{\sqrt{2} M_{\rm pl}} e^{i5\frac{a}{f_a}} + h.c.\right) + ...$$

Naively, the large theta angle is expected

$$\bar{\theta} \sim \mathcal{O}(1) \gg 10^{-10}$$

Gravity disturbs the axion potential !!

Gravity badly and explicitly breaks PQ symmetry

Spontaneous PQ breaking scalar field (Global PQ charge : +1)

$$\Phi \ni \frac{1}{\sqrt{2}} f_{PQ} e^{i\frac{a}{f_a}}$$

a ***: axion***

If phys[illegible]ck scale breaks PQ symmetry

$$\frac{\Phi^5}{M} + h.c....$$

which distorts axion potential

$$V(a) \sim -m_a^2 f_a^2 \cos\left(\frac{a}{f_a}\right) + \left(\frac{\lambda_1}{\sqrt{2}}[illegible]\frac{a}{}} + h.c.\right) + ...$$

Naively, the large theta angle is expected

$$\bar{\theta} \sim \mathcal{O}(1) \gg 10^{-10}$$

Strong CP problem again !!

Gravity disturbs the axion potential !!

Gravity badly and explicitly breaks PQ symmetry

Spontaneous PQ breaking scalar field (Global PQ charge : +1)

$$\Phi \ni \frac{1}{\sqrt{2}} f_{PQ} e^{i \frac{a}{f_a}}$$

a ***: axion***

If phys… …ck scale breaks PQ symmetry

Strong CP problem again !!

How to protect the axion potential??

$$\ldots \left(\ldots \frac{\ldots}{f_a} \right) + \left(\lambda_1 \ldots \sqrt{2} \ldots \frac{a}{\ldots} + h.c. \right) + \ldots$$

Na…, the large theta angle is expected

$$\bar{\theta} \sim \mathcal{O}(1) \gg 10^{-10}$$

Gravity disturbs the axion potential !!

Gauge symmetry to overcome gravity effect

To prohibit the axion potential term induced by gravity

$$\mathcal{L} \ni \frac{\Phi^5}{M_{pl}}$$

One answer : Gauge symmetry '89 Krauss and Wilczek, '95 Intriligator and Seiberg

$\Phi(+1)$: charged under Z12, 13... or U(1)X gauge symmetry

$$\mathcal{L} \ni \cancel{\frac{\Phi^5}{M_{pl}}} \longrightarrow \mathcal{L} \ni \frac{\Phi^{12}}{M_{pl}^8}, \frac{\Phi^{13}}{M_{pl}^9} \cdots$$

Higher discrete gauge symmetry, smaller the shift of theta

$$\checkmark \Delta\bar{\theta} \ll 10^{-10}$$

What is the origin of the gauge symmetry e.g. Z12??

Gauged PQ mechanism (Our proposal)

H. Fukuda, M. Ibe, M. S, and T. T. Yanagida, Phys. Lett. B771, 327 (2017).

Two or more PQ symmetries make a gauge symmetry
U(1)gPQ protecting anomalous global symmetry

e.g. One linear combination of two anomalous symmetry can be anomaly free

U(1)PQ1

cf.ZDFS model
cf. Composite axion model
cf. KSVZ model

U(1)PQ2

cf.ZDFS model
cf. Composite axion model
cf. KSVZ model

$$U(1)_{PQ_1} \times U(1)_{PQ_2} \to U(1)_{gPQ} \times U(1)_{PQ}$$

In recent paper, we found simple model motivated by see saw mechanism

M. Ibe, M. S, and T. T. Yanagida, arXiv:1805.10029.

$$U(1)_{gPQ} = U(1)_{B-L}$$