Lorentz invariant CPT violation†

M. Chaichian,*1 K. Fujikawa,*2 and A. Tureanu*1

A Lorentz invariant CPT violation, which may be termed as the long distance CPT violation in contrast to the familiar short distance CPT violation, has been recently proposed[1)]. This scheme is based on the non-local interaction vertex and characterized by the infrared divergent form factor. We show that Lorentz covariant $T^\star$-product is consistently defined and the energy-momentum conservation is preserved in perturbation theory if the path integral is suitably defined for this non-local theory, although unitarity is generally lost. It is illustrated that T-violation is realized in the decay and formation processes. It is also argued that the equality of masses and decay widths of the particle and anti-particle is preserved if the non-local CPT violation is incorporated either directly or as perturbation by starting with the conventional CPT-even local Lagrangian. However, we also explicitly show that the present non-local scheme can induce the splitting of particle and anti-particle mass eigenvalues if one considers a more general class of Lagrangians.

We study the specific realization of CPT violation

$$\begin{aligned}\mathcal{L} &= \bar{\psi}(x)[i\gamma^\mu\partial_\mu - M]\psi(x) + \frac{1}{2}\partial_\mu\phi(x)\partial^\mu\phi(x)\\ &- \frac{1}{2}m^2\phi(x)^2 + g\bar{\psi}(x)\psi(x)\phi(x) - V(\phi)\\ &+ g_1\bar{\psi}(x)\psi(x)\int d^4y\theta(x^0-y^0)\delta((x-y)^2-l^2)\phi(y)\end{aligned}$$

as a main theoretical model. This Lagrangian is formally hermitian and the term with a small real g_1 and the step function $\theta(x^0-y^0)$ stands for the CTP and T violating interaction; l is a real constant parameter. It is interesting that the CPT and T violating term is real in the present case. We define the interaction part

$$\begin{aligned}\mathcal{L}_I &= g\bar{\psi}(x)\psi(x)\phi(x)\\ &+ g_1\bar{\psi}(x)\psi(x)\int d^4y\theta(x^0-y^0)\delta((x-y)^2-l^2)\phi(y).\end{aligned}$$

We treat this highly non-local Lagrangian in path integral as described in[2)].Namely

$$\begin{aligned}&\langle 0,+\infty|0,-\infty\rangle_J\\ &= \int \mathcal{D}\bar{\psi}\mathcal{D}\psi\mathcal{D}\phi\exp\{i\int d^4x[\mathcal{L}_0+\mathcal{L}_I+\mathcal{L}_J]\}\end{aligned}$$

with the source term $\mathcal{L}_J = \bar{\psi}(x)\eta(x) + \bar{\eta}(x)\psi(x) + \phi(x)J(x)$, and one may generate Green's functions in a power series expansion of perturbation as

$$(i)^n\langle T^\star\phi(x_1)..\phi(x_N)\int d^4y_1\mathcal{L}_I(y_1)..\int d^4y_n\mathcal{L}_I(y_n)\rangle.$$

We use the $T^\star$-product which is essential to make the path integral on the basis of Schwinger's action principle consistent[2)].

The present way to introduce CPT violation is based on an extra form factor in momentum space as

$$\int d^4x\bar{\psi}(x)\psi(x)\int d^4y\theta(x^0-y^0)\delta((x-y)^2-l^2)\phi(y)$$

$$= \int dp_1dp_2dq(2\pi)^4\delta^4(p_1+p_2+q)\bar{\psi}(p_1)\psi(p_2)f(q)\phi(q)$$

with

$$f(q) \equiv \int d^4z\theta(z^0)\delta(z^2-l^2)e^{iqz}$$

namely, CPT violation is realized by a form factor $f(q)$ which becomes complex for time-like momentum. The ordinary local field theory is characterized by $f(q)=1$. The above form factor is infrared divergent, and it is quadratically divergent in the present example. This infrared divergence arises from the fact that we cannot divide Minkowski space into (time-like) domains with finite *4-dimensional* volumes in a Lorentz invariant manner. The Minkowski space is hyperbolic rather than elliptic. CPT symmetry is related to the fundamental structure of Minkowski space, and thus it is gratifying that its possible breaking is also related to the basic property of Minkowski space.

Based on this setting, we confirmed the followings:
1. The present model produces T-violation in the decay $\phi \rightarrow \psi + \bar{\psi}$ and its reversed formation process $\psi + \bar{\psi} \rightarrow \phi$.
2. The equality of masses and decay widths of the particle and anti-particle is preserved if the non-local CPT violation is incorporated either directly or as perturbation by starting with the conventional CPT-even local Lagrangian.

Some of the more realistic applications of the present CPT violation scheme to the particle-antiparticle mass splitting, inparticular, the neutrino-antineutrino mass splitting in the standard model have been already dicussed elsewhere[3,4)].

References

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*1 Department of Physics, University of Helsinki,
*2 RIKEN Nishina Center