Gravity induced CP Violation in K and B mixing, decays and interference experiments

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CPV experiments with neutral flavored mesons

The impact of earth's gravity on neutral mesons dynamics is analyzed. The main effect of a Newtonian potential is to couple the strangeness and bottomness flavor oscillations with the quarks zitterbewegung oscillations.
This coupling is responsible of the observed CP violations in the three types of experiments analyzed here : **(i)** indirect violation in the mixing, **(ii)** direct violation in the decay to one final state and **(iii)** violation in interference between decays with and without mixing.
The 3 violation parameters associated with these experiments are predicted in agreement with the experimental data. The amplitude of the violation is linear with respect to the strength of gravity so that this new mechanism allows to consider matter dominated cosmological evolutions providing the observed baryon asymmetry of the universe.

CPV observables

$Re(\varepsilon),\ Re(\varepsilon'/\varepsilon),\ Sin(2\beta)$

Without CPV : Mass Eigenstates = CP Eigenstates

$$|M_1\rangle = \frac{|M^0\rangle}{\sqrt{2}} + \frac{|\overline{M}^0\rangle}{\sqrt{2}} = \widehat{CP}|M_1\rangle,$$
$$|M_2\rangle = \frac{|M^0\rangle}{\sqrt{2}} - \frac{|\overline{M}^0\rangle}{\sqrt{2}} = -\widehat{CP}|M_2\rangle.$$

With CPV : Experimental Mass Eigenstates

$$|K_S\rangle = |K_1\rangle + \varepsilon|K_2\rangle,\quad |K_L\rangle = |K_2\rangle + \varepsilon|K_1\rangle.$$

$$|B_L\rangle = \cos\beta|B_1\rangle + j\sin\beta|B_2\rangle,\quad |B_H\rangle = \cos\beta|B_2\rangle + j\sin\beta|B_1\rangle.$$

CP basis ⇄ Flavor basis

Mixing : ε

$$|K_S\rangle = \frac{1+\varepsilon}{\sqrt{2}}|K_0\rangle + \frac{1-\varepsilon}{\sqrt{2}}|\overline{K}^0\rangle,\quad |K_L\rangle = \frac{1+\varepsilon}{\sqrt{2}}|K_0\rangle - \frac{1-\varepsilon}{\sqrt{2}}|\overline{K}^0\rangle.$$

$$\frac{\langle\pi^0\pi^0|\mathcal{T}|K_L\rangle}{\langle\pi^0\pi^0|\mathcal{T}|K_S\rangle} \equiv \varepsilon - 2\varepsilon'$$

Decay : ε'

$$|B_L\rangle = \frac{\exp+j\beta}{\sqrt{2}}|B^0\rangle + \frac{\exp-j\beta}{\sqrt{2}}|\overline{B}^0\rangle,\quad |B_H\rangle = \frac{\exp+j\beta}{\sqrt{2}}|B^0\rangle - \frac{\exp-j\beta}{\sqrt{2}}|\overline{B}^0\rangle$$

Interference : Sin(2β)

ΔS = 2 and ΔB' = 2 oscillations on earth

$$j\hbar\frac{d|M(\tau)\rangle}{d\tau} = mc^2|M\rangle - \frac{\widehat{\delta m}}{2}c^2\cdot|M\rangle - j\hbar\frac{\widehat{\gamma}}{2}\cdot|M\rangle + mg\ \widehat{x}(\tau)\cdot|M\rangle$$
(LOY; gravity)

$$\widehat{\delta m} = \delta m\left[|M^0\rangle\langle\overline{M}^0| + |\overline{M}^0\rangle\langle M^0|\right],$$
$$\widehat{\gamma} = \Gamma\left[|M^0\rangle\langle M^0| + |\overline{M}^0\rangle\langle\overline{M}^0|\right] - \delta\Gamma\left[|M^0\rangle\langle\overline{M}^0| + |\overline{M}^0\rangle\langle M^0|\right]$$

$$\widehat{x}(\tau) = \langle q'\overline{q}|\widehat{x}(\tau)|q'\overline{q}\rangle|M^0\rangle\langle M^0| + \langle\overline{q}'q|\widehat{x}(\tau)|\overline{q}'q\rangle|\overline{M}^0\rangle\langle\overline{M}^0| + \langle\overline{q}'q|\widehat{x}(\tau)|q'\overline{q}\rangle|\overline{M}^0\rangle\langle M^0| + \langle q'\overline{q}|\widehat{x}(\tau)|\overline{q}'q\rangle|M^0\rangle\langle\overline{M}^0|$$

$\delta mc^2 \sim 10^{-6} - 10^{-4}$ eV

$mg|\langle|\widehat{x}|\rangle| \sim mg\lambda_C \ll \delta mc^2$

$\hbar g/\delta mc^3 \sim 10^{-19} - 10^{-17}$

$$|M(\tau)\rangle = |N(\tau)\rangle\exp-j\frac{mc^2\tau}{\hbar} + |n(\tau)\rangle\exp-j\frac{mc^2\tau}{\hbar}$$

$$|N\rangle \sim O\left(\hbar g/\delta mc^3\right)^0,\ |n\rangle \sim O\left(\hbar g/\delta mc^3\right)^1$$

LOY
$$j\hbar\frac{d|N\rangle}{d\tau} = -\frac{1}{2}\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)\cdot|N\rangle,$$
Gravity
$$j\hbar\frac{d|n\rangle}{d\tau} = -\frac{1}{2}\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)\cdot|n\rangle + mg\,\widehat{x}\cdot|N\rangle$$

$$j\hbar\frac{d|n\rangle}{d\tau} = -\frac{1}{2}\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)\cdot|n\rangle + 2jmgh\frac{d\widehat{x}}{d\tau}\cdot\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)^{-1}\cdot|N\rangle - 2jmg\hbar\frac{d}{d\tau}\left[\widehat{x}\cdot\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)^{-1}\cdot|N\rangle\right].$$

$$j\hbar\frac{d|N\rangle}{d\tau} = -\frac{1}{2}\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)\cdot|N\rangle,\quad \textbf{LOY}$$
$$j\hbar\frac{d|n\rangle}{d\tau} = -\frac{1}{2}\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)\cdot|n\rangle + j\widehat{G}\cdot|N\rangle$$

Gravity
$$\widehat{G} = 2mg\hbar\left(\frac{d\widehat{x}}{d\tau}\right)\cdot\left(\widehat{\delta m}c^2 + j\hbar\widehat{\gamma}\right)^{-1}$$

Fermions/antifermions Zitterbewegung oscillations

Dirac's equation
$$j\hbar\frac{d\widehat{\mathbf{x}}}{d\tau} = \left[\widehat{\mathbf{x}}, \widehat{H}(\widehat{\mathbf{x}}, \widehat{\mathbf{p}})\right] = j\hbar c\boldsymbol{\alpha}$$

$$\left[\langle q'\overline{q}| \pm \langle\overline{q}'q|\right]\alpha_x\otimes\alpha'_x\left[|q'\overline{q}\rangle \pm |\overline{q}'q\rangle\right] = \pm1,$$
$$\left[\langle q'\overline{q}| \mp \langle\overline{q}'q|\right]\alpha_x\otimes\alpha'_x\left[|q'\overline{q}\rangle \pm |\overline{q}'q\rangle\right] = 0.$$

$$\frac{d\widehat{x}}{d\tau} = c|M^0\rangle\langle\overline{M}^0| - c|\overline{M}^0\rangle\langle M^0|$$
Zitterbewegung

Mixing : ε

CPTV

$$\kappa = \frac{2m_Kg\hbar}{\delta m_K^2c^3}$$

$$|K_1^\oplus\rangle = |K_1\rangle - j\kappa|K_2\rangle,\quad |K_2^\oplus\rangle = |K_2\rangle + j\kappa|K_1\rangle$$

This allows to calculate the gravity induced transition amplitude

$$\Omega_{2\to1} = \left\langle\frac{dK_2^\oplus}{d\tau}\middle|K_1^\oplus(\tau)\right\rangle = \kappa\frac{\delta m_Kc^2}{\hbar}\exp j\frac{\delta m_Kc^2}{\hbar}\tau.$$

$$|K_{L\exp}(\tau)\rangle = a_2(\tau)|K_2\rangle + a_1(\tau)|K_1\rangle$$

$$a_2(\tau)\Omega_{2\to1} = a_1(\tau)\frac{\Gamma_{1\to f}}{2}$$

$$|K_{L\exp}\rangle = |K_2\rangle + \frac{\delta m_Kc^2}{\hbar\Gamma_1/2}\kappa|K_1\rangle$$

$$\mathrm{Re}\,\varepsilon_{\exp} = \frac{\delta m_Kc^2}{\hbar\Gamma_1/2}\frac{2m_Kg\hbar}{\delta m_K^2c^3} = 1.66\times10^{-3}$$

The observed K_L state is a linear superposition of K_2 plus a small amount of K_1 resulting from the balance between gravity induced regeneration Ω and the fast irreversible decay Γ of this K_1 component.

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$$\arg\varepsilon = \arctan\left(2\delta m_Kc^2/\hbar\Gamma_S\right) = 43.4°$$

Bell & Steinberger

Decay : ε'

This usual definition of ε' is invariant under rephasing of the pions state but not with respect to the rephasing of the kaons mass eigenstates. We can define a decay amplitude ratio which is a phase-convention-independent quantity through the multiplication of η_{00} with the factor φ_K

$$\eta_{00} = \frac{\langle\pi^0\pi^0|\mathcal{T}|K_L\rangle}{\langle\pi^0\pi^0|\mathcal{T}|K_S\rangle} \equiv \varepsilon - 2\varepsilon'$$

$$\varphi_K = \frac{\langle K^0|K_S\rangle}{\langle K^0|K_L\rangle} = 1$$

however

$$\varphi_K^\oplus = \frac{\langle K^0|K_1^\oplus\rangle}{\langle K^0|K_2^\oplus\rangle} = 1 - \langle K_1^\oplus|K_2^\oplus\rangle$$

$$\eta_{00}^\oplus\varphi_K^\oplus = \frac{\langle K_1^\oplus|K_2^\oplus\rangle}{2}\left[1 - 2\frac{\langle K_1^\oplus|K_2^\oplus\rangle}{2}\right]$$

$$\mathrm{Re}(\varepsilon'/\varepsilon) = \frac{\delta m_Kc^2}{\hbar\Gamma_1/2}\kappa = 1.66\times10^{-3}$$

Interference : Sin(2β)

$$\widetilde{\lambda}_f = \frac{\langle\overline{B}^0|B_L\rangle}{\langle B^0|B_H\rangle}\frac{\langle f|\mathcal{T}|\overline{B}^0\rangle}{\langle f|\mathcal{T}|B^0\rangle} = \exp-2j\beta\frac{\langle f|\mathcal{T}|\overline{B}^0\rangle}{\langle f|\mathcal{T}|B^0\rangle}$$

$$\chi = \delta m_Bc^2/\hbar\Gamma_B = 0.77,\quad \varsigma = 2m_Bg\hbar/\delta m_B^2c^3\left(\chi + \chi^{-1}\right)$$

$$|B_L^\oplus\rangle = |B_1\rangle - \varsigma(1 + j\chi)|B_2\rangle,\quad |B_H^\oplus\rangle = |B_2\rangle - \varsigma(1 - j\chi)|B_1\rangle$$

is not phase-convention-independent with respect to the mass eigenstates. To set up a fully phase-convention-independent parameter we introduce the CP symmetric rephasing factor

$$\varphi_B = \sqrt{\frac{\langle B_1|B_H\rangle}{\langle B_1|B_L\rangle}\frac{\langle B_2|B_H\rangle}{\langle B_2|B_L\rangle}} = 1$$

however

$$\varphi_B^\oplus = \sqrt{\frac{\langle B_1|B_H^\oplus\rangle}{\langle B_1|B_L^\oplus\rangle}\frac{\langle B_2|B_H^\oplus\rangle}{\langle B_2|B_L^\oplus\rangle}} = \sqrt{\frac{1 - j\chi}{1 + j\chi}}$$

$$\sin2\beta = \sin\left[\arctan(0.77)\right] = 0.61$$

Conclusions

__Type (i)__ CPV observed with K_0 stems from a gravity induced interplay between vertical quarks zitterbewegung oscillations at the velocity of light on the one hand and strangeness oscillations on the other hand.
The small __type (ii)__ CPV observed with K_0 is associated with the CPT invariant modelisation of a gravity induced CPT violation and is elucidated through a careful analysis of the rephasing invariance of the observable η_{00}.
__Type (iii)__ CPV observed with B_0 is associated with the CPT invariant modelisation of a gravity induced CPT violation displaying a very small modulus and a significant phase β.
When the mesons are considered stables, the evolution is unitary and there is no T violation. T violation stems from the modelisation of the transition amplitudes as irreversible decays.
The very large __type (iv)__ CPV observed in our universe, namely its baryon-antibaryon asymmetry, remains an open issue within the KM framework of interpretation, although gravity induced CPV displays the potential to set up cosmological evolution models in agreement with the present state of our universe.
We have demonstrated that gravity induced CPV allows to predict experimental CPV parameters and appears to provide the potential to explain the baryon asymmetry of the universe as its amplitude is linear with respect to the strength of gravity.This set of new results was obtained within the canonical framework of quantum mechanics, on earth, without any speculative assumption on new coupling, or new field, or new physics. From this clear convergence of results, we can conclude that a CKM matrix free of CPV phase is to be considered as the core of the SM in a flat Lorentzian environment far from any massive object like earth.

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