detailed balance.

The first test come to our mind.

$$a + b \rightarrow c + d$$

and its reverse $\quad c + d \rightarrow a + b$

★ Time reversal sym $\xrightarrow{\text{implies}}$ detailed balance.

(sufficient but not necessary!) $\quad \xleftarrow{\times}$ not necessary

Eg

① If $\not\pi$ interaction ΔH is so weak, only only the first order perturbation matters, the Hermiticity of ΔH is sufficient to ensure

$$|\langle cd|\Delta H|ab\rangle|^2 = |\langle ab|\Delta H|cd\rangle|^2$$

② Parity V, T X, can still yield detailed balance.

consider elastic πN scattering

$$\pi_i + N_i \rightarrow \pi_f + N_f$$

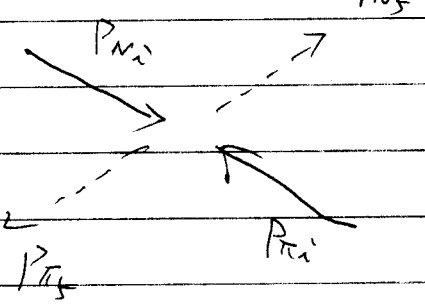
~~2 spin D.O.F~~ $\rightarrow$ 2 spin D.O.F.

$\Rightarrow 2 \times 2 = 4$ form factors to describe the whole process at CM frame.

In CM,

$$\vec{J}_i = \vec{J}_f \Rightarrow (\vec{\sigma}_i = \vec{\sigma}_f)$$

and $\quad \vec{P}_{N_i} + \vec{P}_{\pi_i} = \vec{P}_{N_f} + \vec{P}_{\pi_f}$



Transition amplitude

$$T \propto g_1(s,t) + g_2(s,t)\left(\vec{p}_{N_i} + \vec{p}_{\pi_i}\right)\cdot\vec{\sigma} + g_3(s,t)\left(\vec{p}_{N_i} - \vec{p}_{\pi_i}\right)\cdot\vec{\sigma} + g_4(s,t)\left(\vec{p}_{N_i}\times\vec{p}_{N_f}\right)\cdot\vec{\sigma}$$

under T reversal	under parity
$\vec{\sigma} \leftrightarrow -\vec{\sigma}$	$\vec{\sigma} \leftrightarrow \vec{\sigma}$
$\vec{p}_{\pi_i} \leftrightarrow -\vec{p}_{\pi_f}$	$\vec{p} \leftrightarrow -\vec{p}$
$\vec{p}_{N_i} \leftrightarrow -\vec{p}_{N_f}$	

	T	P
g_1	✓	✓
g_2	✓	✗
g_3	✗	✗
g_4	✓	✓

even $\not\Pi$, the $\not P$ ~~invariant~~ can kill g_3 (and g_2) to ensure the detailed balance.

EDM (electric dipole moment)

In classical EDM, $\vec{d} \propto \int \vec{r}\rho(r)\,d^3r$, $H = -\vec{d}\cdot\vec{E}$

For point particle, no volume, by Wigner-Eckart theorem, the only vector can be associated to is spin.

$$\Rightarrow \vec{d} \propto \vec{S}$$

Π

$\vec{S} \rightarrow -\vec{S}$

$\vec{J} \rightarrow -\vec{J}$

$\vec{E} \Rightarrow +\vec{E}$

$\vec{d}\cdot\vec{E} \xrightarrow{\Pi} (-\vec{J})\cdot\vec{E}$

P $\quad (+\vec{J})\cdot(-\vec{E})$ $\quad$ C

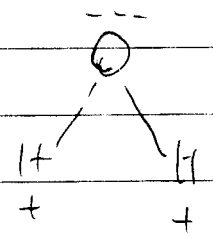
EDM violates both Π & CP

exp limit $\quad |d_e| < 10^{-27}$ e-cm

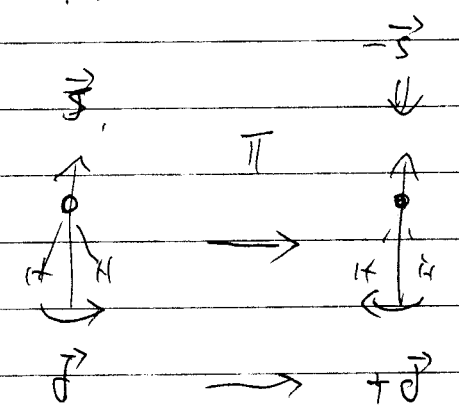
$|d_n| < 10^{-26}$ e-cm

* However, if degenerate ground states transform into each other under parity, then EDM doesn't imply T violation.

consider $|+\rangle \neq 0$



$\vec{J} \neq 0$



CPT theorem : { Local theorem, Lorentz inv.

statistics { Bose-Einstein, boson

Fermi-Dirac, fermion

$\Rightarrow \Pi = \cancel{CP}$

- ~~CP~~ TM
  - K^0-$\bar{K}^0$ mixing, Cronin & Fitch
  - B^0-$\bar{B}^0$ mixing, Babar / SLAC
    Belle / KEK

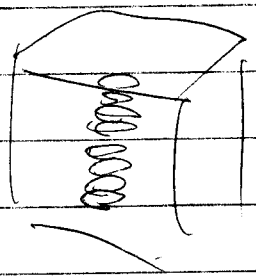
- Matter - antimatter asymetry of the universe -

Time reversal vs. arrow of time

Π $\longleftrightarrow$ 2nd law of thermodynamics.

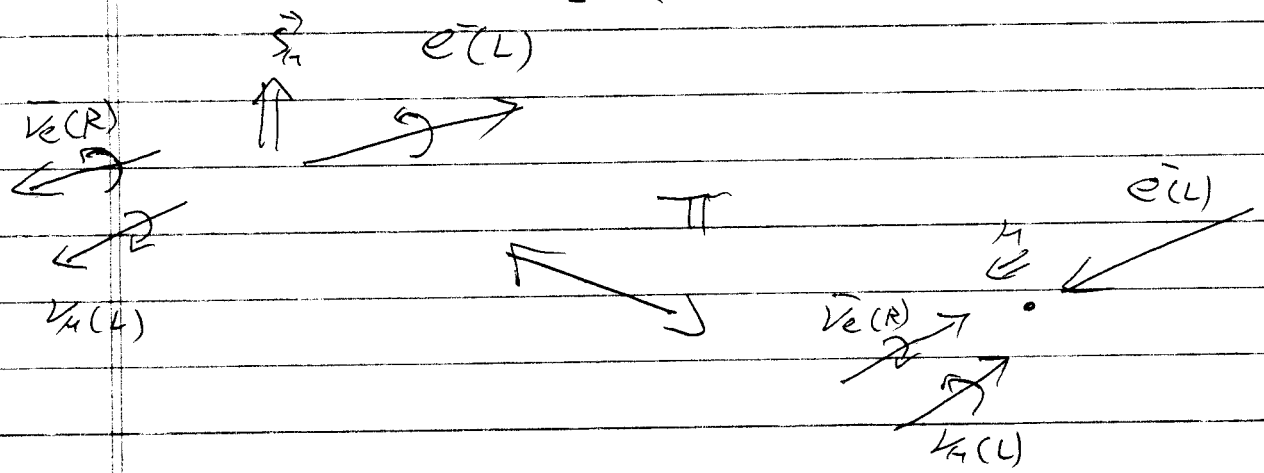
fundamental process — initial condition

① Classical



1000 coins, facing up, in a pile
after shaking, no change to return to the initial state.

② HEP: $\mu(\Uparrow) \to e_L \bar{\nu}_{eR} \nu_{\mu L}$



reverse the final state, $e_L^- + \bar{\nu}_{eR} + \nu_{\mu L} \to \mu(\Leftarrow) \neq \mu(\Uparrow)$

③ Stern-Gerlach exp