

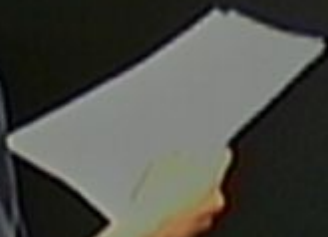
Title: Baryogenesis and Leptogenesis

Date: Apr 19, 2010 02:00 PM

URL: <http://pirsa.org/10040077>

Abstract:

What is puzzle?



1) What is puzzle?

a) Before Sakharov

b) After Sakharov

3) c

1) What is puzzle?

2) a) Before Sakharov

b) After Sakharov

3) Classical GUT Baryogenesis

1) What is puzzle?

2) a) Before Sakharov

b) After Sakharov

3) Classical GUT Baryogenesis

4) Non-perturbative SM B, L

5)

- 1) What is puzzle?
- 2) a) Before Sakharov
b) After Sakharov
- 3) Classical GUT Baryogenesis
- 4) Non-perturbative SM B, L
- 5) Leptogenesis

Prognosis

9
L
R

Prognosis

$\frac{1}{2} \rightarrow \frac{1}{3}$
 $\frac{1}{3} \rightarrow \frac{1}{4}$

Prognosis

q
 $u \rightarrow d$
 $b \rightarrow \bar{s}$
 $n, p \quad b = 1$
 $\bar{n}, \bar{p} \quad b = -1$

$L = +1$



prognosis

1) What is the puzzle?

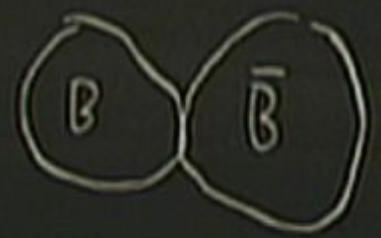
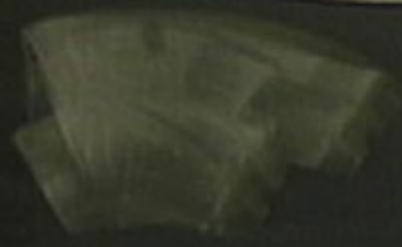
$L=+1$

prognosis

1) What is the puzzle?

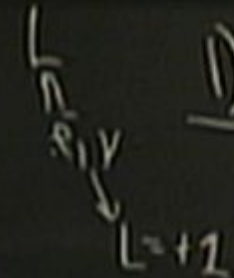
9
5
3
2

$L=+1$



Prognosis

q
 u, d
 $b, \bar{3}$
 $n, p \quad b=1$
 $\bar{n}, \bar{p} \quad b=-1$

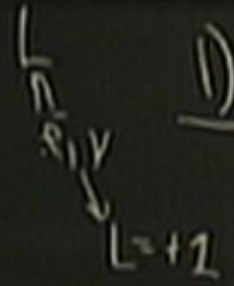


1) What is the puzzle?



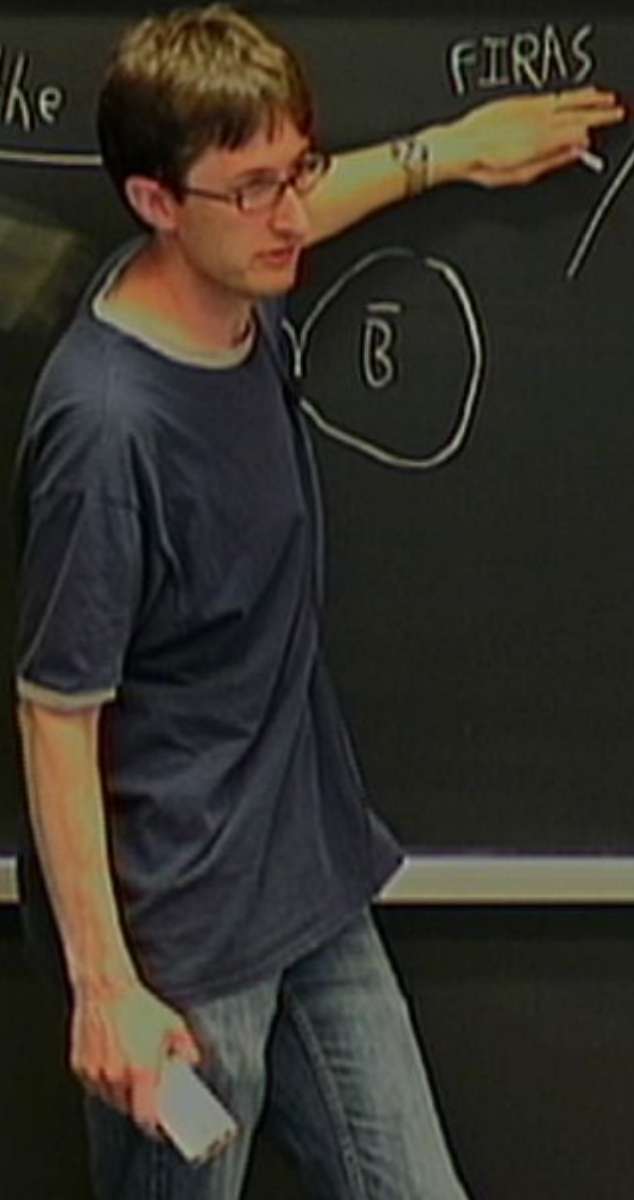
Prognosis

q
 u, d
 $b, \bar{3}$
 $n, \bar{p} \quad b=1$
 $\bar{r}, \bar{p} \quad b=-1$



1) What is the

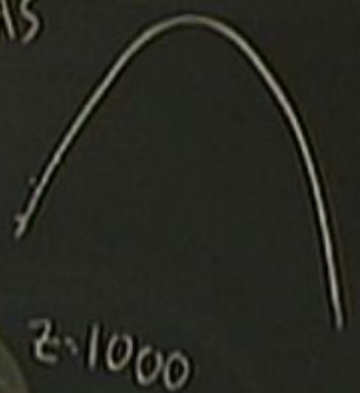
FIRAS



prognosis

is the puzzle?

FIRAS

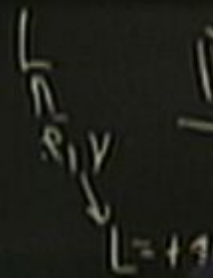


q
 u, d
 b, \bar{s}
 n, p $b=1$
 \bar{n}, \bar{p} $b=-1$

$L=+1$

prognosis

q
 u, d
 $b, \bar{3}$



1) the puzzle?

n, p $b=1$
 R, \bar{p} $b=-1$

$L = \log_2 n$

1) What is the puzzle?

$L = +1$

$$\frac{n_B}{n_X} = 6 \times 10^{10}$$

Prognosis

is the puzzle?

q
 u, d
 $b = \frac{1}{3}$
 n, \bar{p} $b = 1$
 \bar{n}, \bar{p} $b = -1$

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

CMB

BBN



Prognosis

What is the puzzle?

g
 u, d
 $b, \bar{3}$
 n, \bar{p}
 \bar{p}, \bar{b}

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

CMB

BBN



$\rho = \rho_{10^9} = \rho_{\text{today}}$

What is the puzzle?



log-prognosis

1) What is the puzzle?

$L=+1$

$$\left[\frac{n_B}{n_\gamma} \right] = 6 \times 10^{-10} \begin{matrix} \rightarrow \text{CMB} \\ \rightarrow \text{BBN} \end{matrix}$$

$$\left[\frac{n_B}{n_\gamma} \right] \rightarrow \frac{n_{\bar{b}}}{n_\gamma} = \frac{n_{\bar{l}}}{n_\gamma} \approx 10^{-11}$$

$T > 5 \text{ MeV}$



prognosis

1) What is the puzzle?

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

→ CMB
→ BBN

$$\frac{n_b}{n_\gamma} = \frac{n_{\bar{b}}}{n_\gamma} \approx 10^{-11}$$

$T > 5 \text{ MeV}$ $e^- e^+$



$\log = \log 10$

$L = +1$

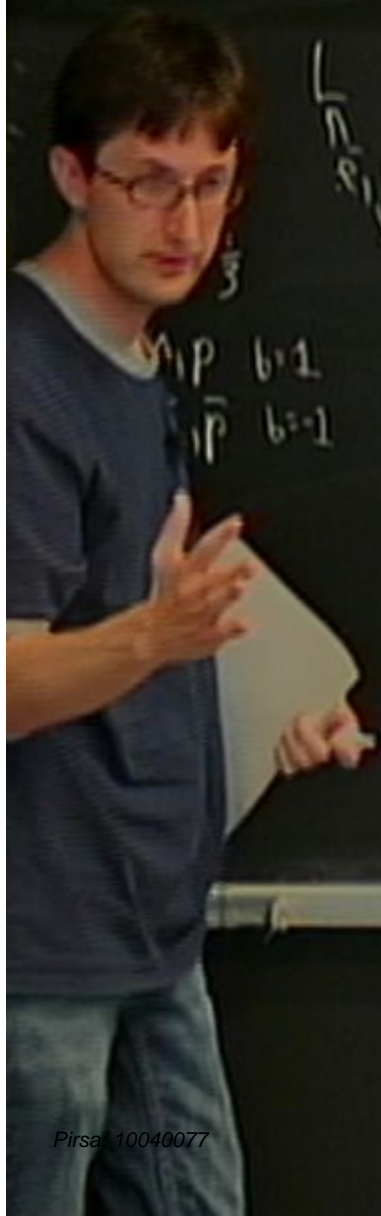
1) What is the puzzle?

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

→ CMB
→ BBN

$$\frac{n_b}{n_f} = \frac{n_{\bar{b}}}{n_{\bar{f}}} \approx 10^{-11}$$

$T > 5 \text{ MeV}$ $e^- e^+$



$\log = \log$

1) What is the puzzle?

$L = +1$

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

CMB

BBN

$$\frac{n_b}{n_\gamma} = \frac{n_{\bar{b}}}{n_\gamma} \approx 10^{-11}$$

$T > .5 \text{ MeV}$ $e^- e^+$



protonesis

What is the puzzle?

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

→ CMB
→ BBN

$$\frac{n_b}{n_l} = \frac{n_{\bar{b}}}{n_{\bar{l}}} \approx 10^{-11}$$

$T > 5 \text{ MeV}$ $e^- e^+$
 $T \approx 6 \text{ GeV}$ $q \bar{q}$



Prognosis

q
 u, d
 $b: \frac{1}{3}$
 $L=+1$
 $n, \bar{p} \quad b=1$
 $\bar{n}, \bar{p} \quad b=-1$

1) What is the puzzle?

$\frac{n_0}{n_\gamma} = 6 \times 10^{-10}$

→ CMB
 → BBN

$\frac{n_b}{n_\gamma} = \frac{n_{\bar{b}}}{n_\gamma} \approx 10^{-11}$

$T > 5 \text{ MeV}$
 $T \approx 6 \text{ GeV}$

$e^- e^+$
 $q \bar{q}$



$$N_i(T) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\exp\left[\frac{E}{T} \pm 1\right]}$$

m_i , fermion

$$N_i(T) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\exp\left[\frac{E}{T}\right] \pm 1}$$

m_i , fermion

$$\frac{1}{h} = C - \epsilon_B = 1$$

$$N_i(T) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\exp[\beta(E - \mu)] \pm 1} \approx \downarrow T^3$$

m_i , fermion

$$[T] = [m] \cdot [E] = [L]^{-1} \cdot [T]$$



$$k = C - \epsilon_B = 1$$

$$N_i(T) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\exp\left[\frac{E}{T}\right] \pm 1} \sim \downarrow T^3$$

m_i , fermion

$$[T] = [m] \cdot [E] = [L]^{-1} \cdot [T]^{-1}$$

Old Answer:

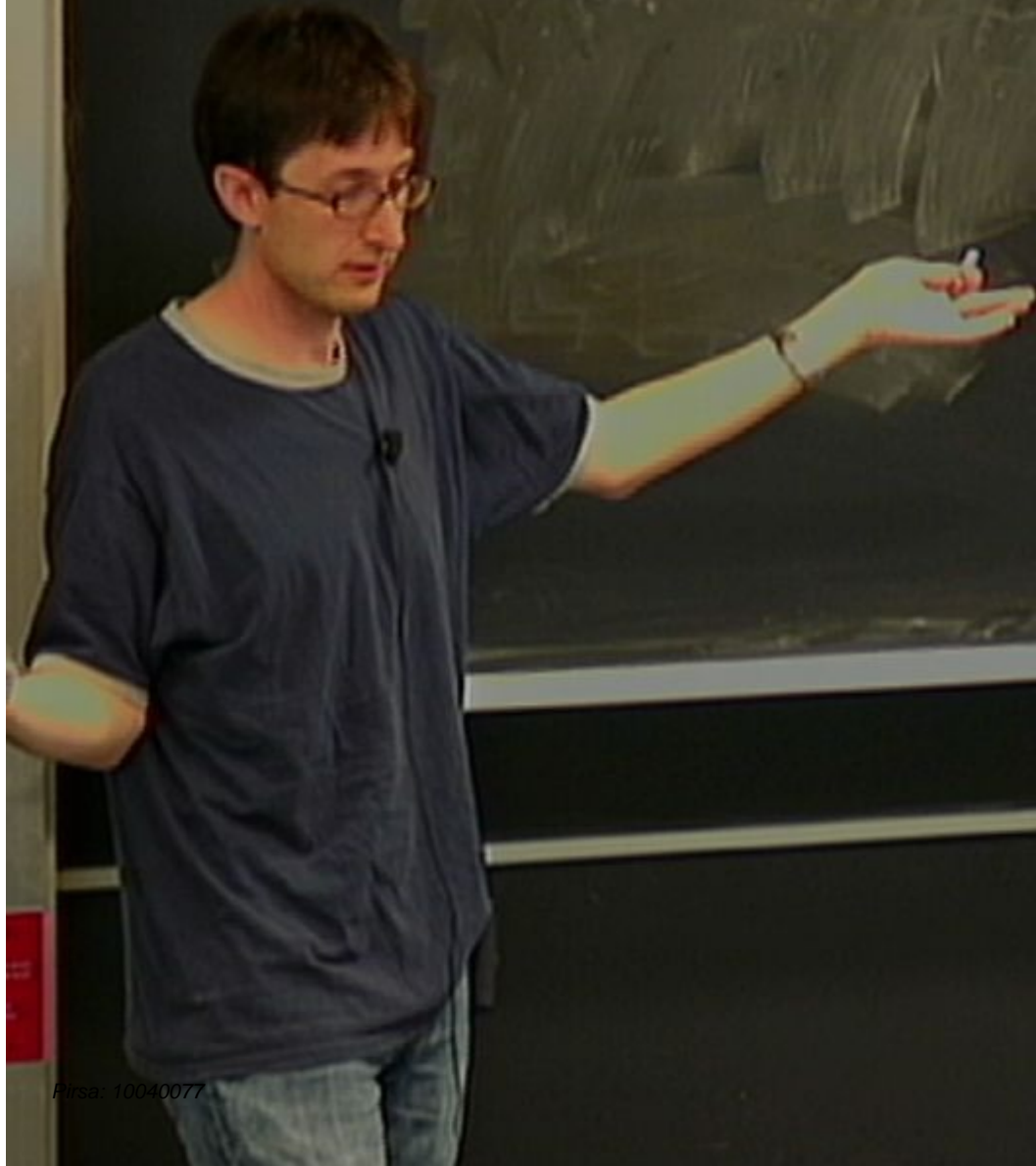


Old Answer: B

$$p^+ \rightarrow e^+ \pi^0$$



Old Answer: B



Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\frac{n_B}{n_S}$$

[Large area of the chalkboard is heavily scribbled out with white chalk.]



Old Answer: $B \neq 0$ initially

$$\frac{nB}{k} \quad \frac{nB}{nS} \times 1$$

Old Answer: $B \neq 0$ initially

$$\frac{nB}{n_0}$$

$$\left[\frac{nB}{n_0} \right] \times 1$$

$\log = \text{analysis}$

What is the puzzle?

$$\frac{n_b}{n_\gamma} = 6 \times 10^{-10}$$

CMB

BBN



$$\frac{n_b}{n_\gamma} = \frac{n_{\bar{b}}}{n_\gamma} \approx 10^{-11}$$

5 MeV

5 eV

$e^- e^+$

$q \bar{q}$

u, d, s
 b, c, t
 n, \bar{n}
 \bar{n}, \bar{p}

Barryogenesis

4) Non-perturbative SM \bar{s}, \bar{t}

5) Leptogenesis

$$\frac{\beta}{V} = n_B \sim a^{-3}$$

1) What is the β ?

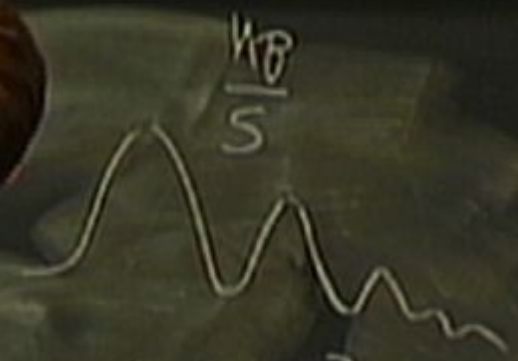
q
 u, d
 $b: \frac{2}{3}$
 $n, p: b=1$
 $\bar{u}, \bar{p}: b=-1$
 $L = +1$

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

$$[B][\bar{L}] \rightarrow \frac{n_B}{n_\gamma}$$

$T > 5 \text{ MeV}$
 $T > 10 \text{ GeV}$

$e\bar{e}$
 $q\bar{q}$



$$\begin{aligned}
 n &\sim \left(\frac{\beta}{s} \right) T^3 \\
 s &\sim \left(\frac{\beta}{s} \right) T^3
 \end{aligned}$$

4) Non-perturbative SM δ, ν

5) Leptogenesis

$$\frac{\rho}{v} = n_B \sim a^3$$

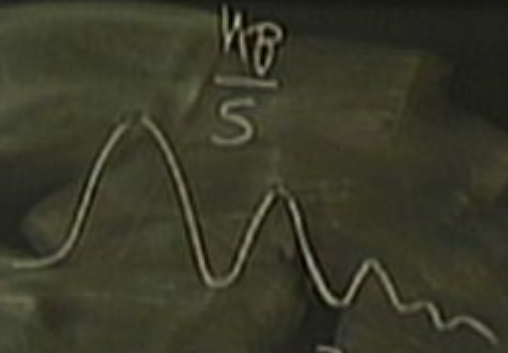
$S =$

1) the puzzle?

$q \rightarrow u, d$
 $b: \frac{1}{3}$
 $n, \bar{p} \quad b=1$
 $\bar{q}, \bar{p} \quad b=-1$

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

\rightarrow CMB
 \rightarrow BBN



$$\begin{aligned}
 n &\sim (\dots) T^3 \\
 S &\sim (\dots) T^3
 \end{aligned}$$

4) Non-perturbative SM δ, ν

5) Leptogenesis

$$\frac{\rho}{V} = n_B \sim a^3$$

$$s = \frac{S}{V} \propto a^{-3}$$

1) What is the puzzle?

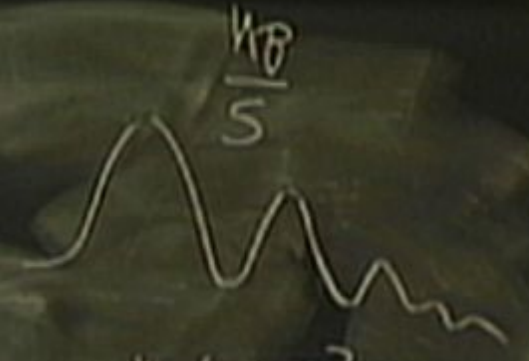
$L = +1$

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

CMB

BBN

$$\frac{n_b}{n_r} = \frac{n_{\bar{l}}}{n_\gamma} \approx 10^{-11}$$



$$n \sim () T^3$$

$$s \sim () T^3$$

$T > 5 \text{ MeV}$
 $T < 6 \text{ eV}$

$e^+ e^-$
 $q \bar{q}$

4) Non-perturbative SM \bar{s}, \bar{t}

5) Leptogenesis

$$\frac{B}{V} = n_B \sim a^3$$

$$S = \frac{S}{V} \propto a^{-3}$$

q
 u, d
 b, \bar{s}
 $n, \bar{p} \quad b=1$
 $\bar{n}, \bar{p} \quad b=-1$

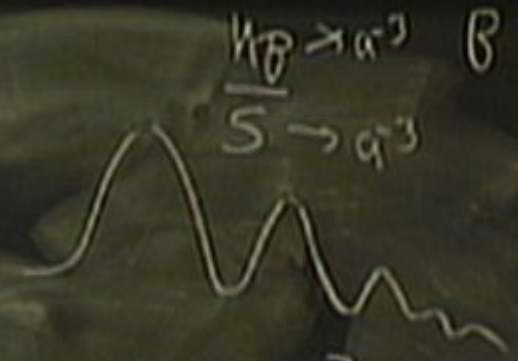
$L = +1$
 $L = -1$

1) What is the...

$$\frac{n_B}{n_\gamma} = 6$$

CMB

BBN



$$n \sim () T^3$$

$$S \sim () T^3$$

$T > 5 \text{ MeV}$
 $T > 6 \text{ GeV}$

... baryogenesis

4) Non-perturbative SM \bar{s}, \bar{t}

5) Leptogenesis

$$\frac{B}{V} = n_B \sim a^3$$

$$S = \frac{S}{V} \propto a^{-3}$$

1) What is the puzzle?

q
 u, d
 b, \bar{s}
 $n, \bar{p} \quad b=1$
 $\bar{r}, \bar{p} \quad b=-1$

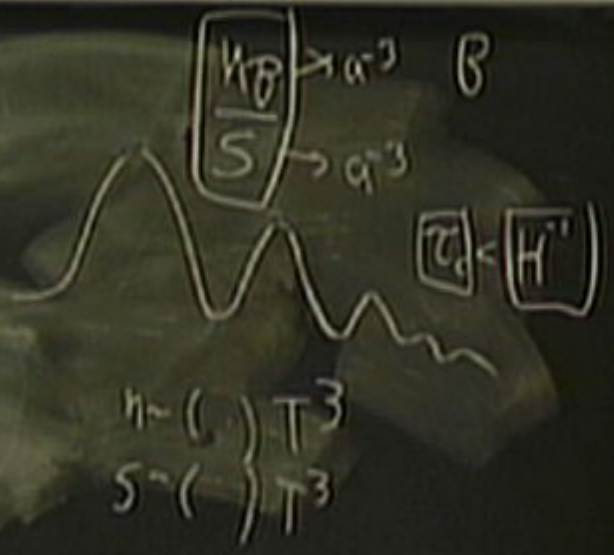
$L = +1$
 $L = -1$

$$\frac{n_B}{n_\gamma} = 6 \times 10^{-10}$$

CMB
BBN

$$\frac{n_B}{n_\gamma} = \frac{n_{\bar{t}}}{n_\gamma} \approx 10^{-11}$$

$T > 5 \text{ MeV}$
 $T \gtrsim 6 \text{ GeV}$
 $e^+ e^-$
 $q \bar{q}$



Old Answer: $B \neq 0$ initially

$$\frac{NB}{NY}$$

$$\left[\frac{NB}{S} \right] \times 1$$

~~[Large scribbled-out text]~~

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakharov:

Old Answer: $B \neq 0$ initially

$$\frac{nB}{n_0}$$

$$\left[\frac{nB}{S} \right] \times 1 \sim 10^{11}$$

Sakhorov:

f



Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-1}$$

Sakhorov:

$$f(\vec{x}, \vec{p}, t)$$


Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakhorov:

$$f(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p}$$


$$d^3\vec{x} d^3\vec{p}$$


Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_g}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-1}$$

Nov:

$$f(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} =$$


$$d^3\vec{x} d^3\vec{p}$$


Old Answer: $B \neq 0$ initially

$$\frac{nB}{n_0}$$

$$\left[\frac{nB}{S} \right] \times 1 \sim 10^{-1}$$

Nov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t)$$


$$d^3\vec{x} d^3\vec{p}$$

Old Answer: $B \neq 0$ initially

$$\frac{nB}{n_0}$$

$$\left[\frac{nB}{S} \right] \times 1 \sim 10^{-11}$$

Sakharov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakho

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t)$$

$$\sqrt{-g^{(3)}} d^3\vec{x}$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakh

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t)$$

$$\sqrt{-g^{(3)}} d^3\vec{x} \int$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakhorov

$$\int d^3\vec{x} d^3\vec{p} = f_i(p, t) d^3\vec{x} d^3\vec{p}$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(\vec{p}, t) d^3\vec{x} d^3\vec{p}$$

$$f_i(\vec{p}, t_x) = \bar{f}_i(\vec{p}, t_x) = f(\vec{p}, t_x)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t) d^3x d^3p$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-11}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(\vec{p}, t) d^3\vec{x} d^3\vec{p} \quad n_B =$$

$$f_i(\vec{p}, t_x) = \bar{f}_i(\vec{p}, t_x)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_A}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x)$$

$$\frac{n_B(t)}{n_A(t)} = \int d^3p$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_A}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-9}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(S, t)} = \sum_i \int d^3p f_i(p, \vec{x}, t) v_i$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x)$$

$$n_B^{(x,t)} = \sum_i \int d^3p [f_i(p, \vec{x}, t) b_i + \bar{f}_i(p, \vec{x}, t) b_i]$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{r}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$f_i(p, t_x) \Rightarrow n_B = 0$$

$$n_B(t_f) \neq 0$$

$$n_B^{(S, t)} = \sum_i \int d^3p [f_i(p, t) b_i + \bar{f}_i(p, t) \bar{b}_i]$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(t_f)} = \int d^3p [f_i(p, t_f) b_i + \bar{f}_i(\vec{p}, t_f) \bar{b}_i]$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x) \Rightarrow n_B = 0$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_T}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x$$

$$f_i(p, t) d^3x d^3p$$

$$n_B^{(B, T)} = \sum_i \int d^3p [f_i(p, \vec{x}, t) b_i + \bar{f}_i(\vec{p}, \vec{x}, t) \bar{b}_i]$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x) \Rightarrow$$

$$f_i(p, t_x) \xrightarrow{C} \bar{f}_i(p, t_x)$$

$$f_i(p, t_x) \neq \bar{f}_i(p$$

$$\bar{f}_i(p, t_x) \xrightarrow{S} f_i(p, t_x)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p$$

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p$$

$$n_B^{(B,1)} = \sum_i \int d^3p [f_i(\vec{p}, \vec{x}, t) b_i + \bar{f}_i(\vec{p}, \vec{x}, t) \bar{b}_i]$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x) \Rightarrow n$$

$$f_i(p, t_x) \xrightarrow{C} \bar{f}_i(p, t_x)$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad +0$$

$$\bar{f}_i(p, t_x) \xrightarrow{S} f_i(p, t_x)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(B,1)} = \int d^3p [f_i(p, \vec{x}, t) b_i + \bar{f}_i(\vec{p}, \vec{x}, t) \bar{b}_i]$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x) \Rightarrow n_B = 0$$

$$f_i(p, t_x) \xrightarrow{C} \bar{f}_i(p, t_x):$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

$$\bar{f}_i(p, t_x) \xrightarrow{C} f_i(p, t_x):$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(i)} = \int d^3p [f_i(p, t) b_i + \bar{f}_i(\vec{p}, t) \bar{b}_i]$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x) \Rightarrow n_B = 0$$

$$f_i(p, t_x) \xrightarrow{C} \bar{f}_i(p, t_x):$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

$$\bar{f}_i(p, t_x) \xrightarrow{S} f_i(p, t_x):$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(\vec{x}, t) d^3\vec{x} d^3\vec{p}$$

$$n_B^{(i,t)} = \int d^3\vec{p} [f_i(\vec{p}, \vec{x}, t) b_i + \bar{f}_i(\vec{p}, \vec{x}, t) \bar{b}_i]$$

$$f_i(\vec{p}, t_x) = \bar{f}_i(\vec{p}, t_x) \Rightarrow n_B = 0$$

$$f_i(\vec{p}, t_f) \neq \bar{f}_i(\vec{p}, t_f)$$

$$\begin{aligned} f_i(\vec{p}, t_x) &\xrightarrow{CP} \bar{f}_i(\vec{p}, t_x) : \\ \bar{f}_i(\vec{p}, t_x) &\xrightarrow{CP} f_i(\vec{p}, t_x) : \\ f_i(\vec{p}, t_f) &\xrightarrow{CP} \bar{f}_i(\vec{p}, t_f) : \\ \bar{f}_i(\vec{p}, t_f) &\xrightarrow{CP} f_i(\vec{p}, t_f) : \end{aligned}$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_T}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

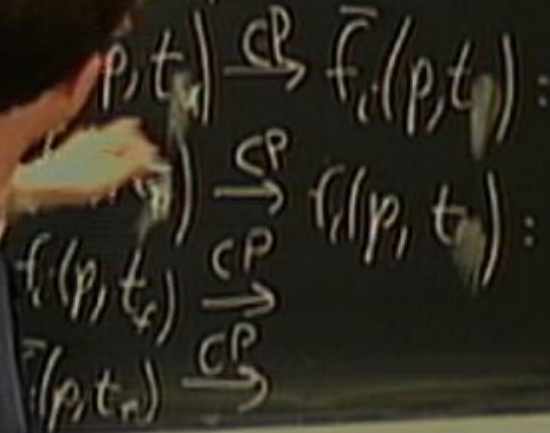
Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p}$$

$$n_B^{(i)} = \int d^3\vec{p} [f_i(\vec{p}, \vec{x}, t) b_i + \bar{f}_i(\vec{p}, \vec{x}, t) \bar{b}_i]$$

$$f_i(\vec{p}, t_x) = \bar{f}_i(\vec{p}, t_x) \Rightarrow n_B = 0$$

$$f_i(\vec{p}, t_f) \neq \bar{f}_i(\vec{p}, t_f) \quad n_B(t)$$



Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_T}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$
$$\vec{p} \rightarrow -\vec{p}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) \cdot d^3x \cdot d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(i)} = \int d^3p [f_i(p, \vec{x}, t) b_i + \bar{f}_i(\vec{p}, \vec{x}, t) \bar{b}_i]$$

$$f_i(p, t_x) = \bar{f}_i(p, t) \approx 0$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad v(t_f) \neq 0$$

$$t_x \left\{ \begin{array}{l} f_i(p, t_x) \xrightarrow{CP} \bar{f}_i(p, t_x) \\ \bar{f}_i(p, t_x) \xrightarrow{CP} f_i(p, t_x) \end{array} \right.$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_X}$$

$$\left[\frac{n_B}{S} \right]_{x=1} \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

Sakhorov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(\vec{p}, t) d^3\vec{x} d^3\vec{p}$$

$$n_B^{(t_f)} = \int d^3\vec{p} [f_i(\vec{p}, \vec{x}, t_f) b_i + \bar{f}_i(\vec{p}, \vec{x}, t_f) \bar{b}_i]$$

$$f_i(\vec{p}, t_f) = \bar{f}_i(\vec{p}, t_f) \Rightarrow n_B = 0$$

$$f_i(\vec{p}, t_f) \neq \bar{f}_i(\vec{p}, t_f) \quad n_B(t_f) \neq 0$$

$$t_f \left\{ \begin{array}{l} f_i(\vec{p}, t_f) \xrightarrow{CP} \bar{f}_i(\vec{p}, t_f) \\ \bar{f}_i(\vec{p}, t_f) \xrightarrow{CP} f_i(\vec{p}, t_f) \end{array} \right.$$

$$f_i(\vec{p}, t_f) \xrightarrow{CP} \bar{f}_i(\vec{p}, t_f)$$

$$\bar{f}_i(\vec{p}, t_f) \xrightarrow{CP} f_i(\vec{p}, t_f)$$

$$f_i(\vec{p}, t_f) \xrightarrow{CP} f_i(\dots)$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_T}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

P, C, T

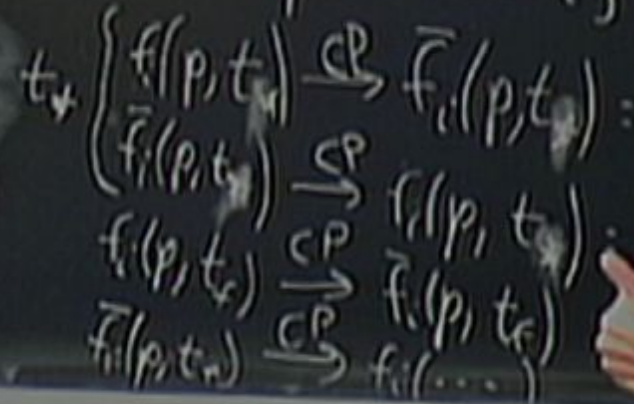
Sakhorov:

$$f(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(i)} = \int d^3p [f_i(p, t) b_i - \bar{f}_i(\vec{p}, t) b_i]$$

$$f(p, t_*) = \bar{f}_i(p, t_*) \Rightarrow n_B = 0$$

$$f(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$



Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_T}$$

$$\left[\frac{n_B}{n_T} \right]_{t=1} \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

P, C, T

Sakhorov:

$$f(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

$$n_B^{(f, t)} = \int d^3p [f_i(p, t) b_i - \bar{f}_i(\vec{p}, t) b_i]$$

$$f(p, t_f) = \bar{f}_i(p, t_f) \Rightarrow n_B = 0$$

$$f(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

$$t_f \begin{cases} f(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f) \\ \bar{f}_i(p, t_f) \xrightarrow{CP} f(p, t_f) \\ f(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f) \\ \bar{f}_i(p, t_f) \xrightarrow{CP} f(p, t_f) \end{cases}$$

Old Answer: $B \neq 0$ initially

$$\frac{n_B}{n_T}$$

$$\left[\frac{n_B}{n_T} \right]_{t=1} \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

P, C, T

Sakharov:

$$f(\vec{x}, \vec{p}, t) d^3x d^3p = f_i(p, t) d^3x d^3p$$

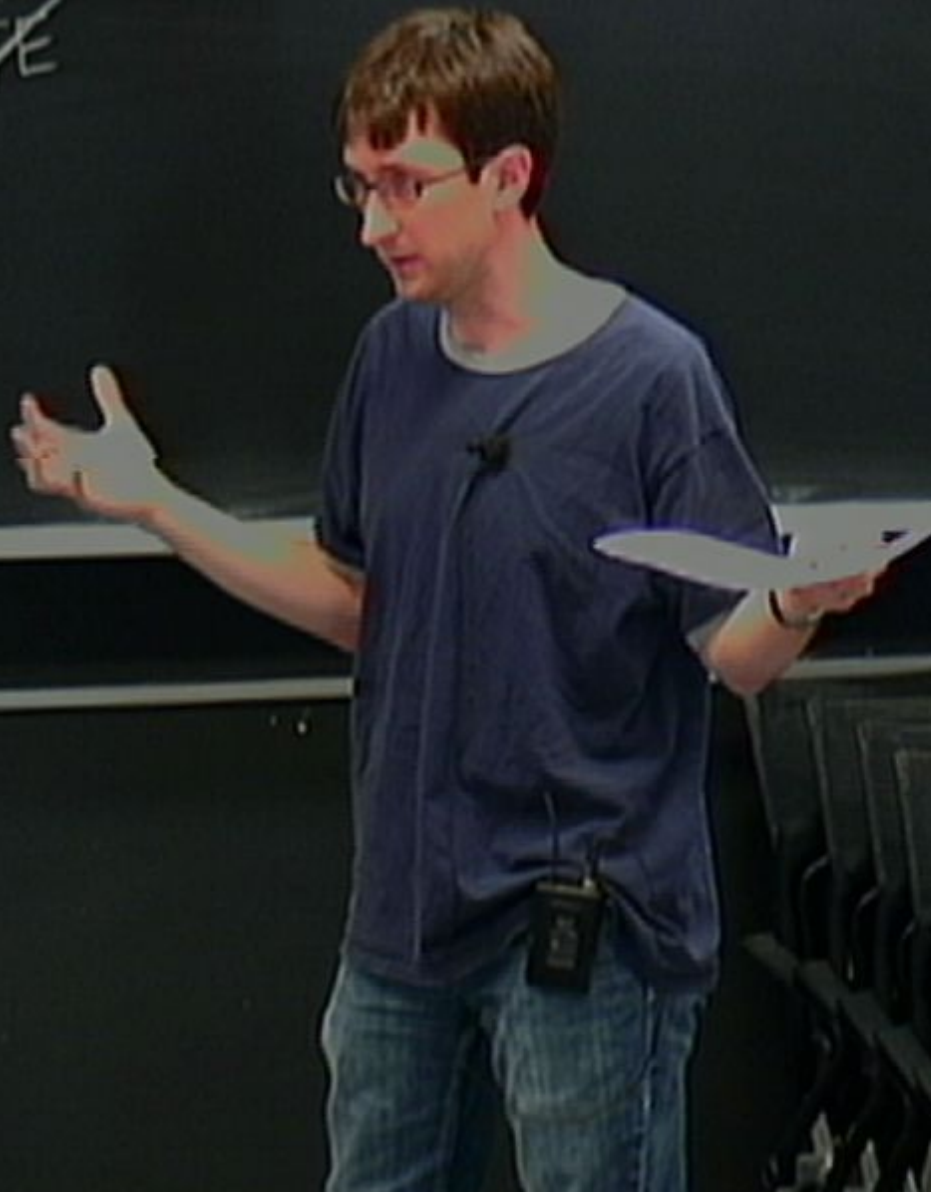
$$n_B^{(t_f)} = \int d^3p [f_i(p, t_f) - \bar{f}_i(p, t_f)]$$

$$f(p, t_f) = \bar{f}_i(p, t_f) \Rightarrow n_B = 0$$

$$f(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

$$t_f \begin{cases} f(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f) \\ \bar{f}_i(p, t_f) \xrightarrow{CP} f_i(p, t_f) \\ f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f) \\ \bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots) \end{cases}$$

- 1) ~~P~~
- 2) ~~X, SP~~
- 3) ~~TE~~



1) 1976 't Hooft
 $\mathbb{R} \quad \mathbb{K}$

$$T: (p, t_f) \rightarrow (p, t_f) \quad \text{with } t_f \neq 0$$

$$\begin{aligned} f(p, t_f) &\xrightarrow{CP} \bar{f}(p, t_f) \\ \bar{f}(p, t_f) &\xrightarrow{CP} f(p, t_f) \end{aligned}$$

1) 1976 't Hooft (B-L)

$$T_i(p, t_f) \quad \text{or } (C_f) \neq 0$$
$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$
$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

$$T_2(p, t_f) \quad \text{or } (f) \neq 0$$

$$f(p, t_f) \xrightarrow{CP} \bar{f}(p, t_f)$$

$$\bar{f}(p, t_f) \xrightarrow{CP} f(\dots)$$

1) 1976 't Hooft (B-L) ~~(B+L)~~

$$T_i(p, t_f) \quad \text{or } (f) \neq 0$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

1) 1976 't Hooft (B-L) ~~(B+L)~~

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT

$$T_i(p, t_f) \quad \sigma(t_f) \neq 0$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

6 't Hooft (B-L) ~~(B+L)~~

Left SU(3) x SU(2) x U(1)

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$

$$T_i(p, t_f) \quad \text{with } \langle \psi_f | \neq 0$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$
- 3) GUT

$$T_i(p, t_f) \quad \text{with } \partial(\mathcal{L}_f) \neq 0$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

- 1) 1976 Gouffé (B-L) ~~(B+L)~~
- 2) EFT $U(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi LL$, $\frac{1}{M^2} QQQL$
- 3) $SU(5)$ $X \begin{matrix} \nearrow^{qq} \\ \searrow^{\bar{q}\bar{l}} \end{matrix}$

$$T_i(p, t_f) \quad \text{with } \partial(p_f) \neq 0$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$
- 3) GUT: $SU(5)$
 - $\chi \rightarrow \bar{q} q$ $(B = \frac{2}{3}, L = 0)$
 - $\chi \rightarrow \bar{q} \bar{l}$ $(B = \frac{1}{3}, L = -1)$

1) 1976 't Hooft (B-L) ~~(B+L)~~

2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$

3) GUT: $SU(5)$ $\chi \begin{cases} \nearrow^{99} (B = \frac{2}{3}, L = 0) \\ \searrow^{9\bar{3}} (B = \frac{1}{3}, L = -1) \end{cases}$

4) BH evaporation

$f_i(p, t_f) \neq 0$ $f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$
 $\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$

1) 1971 Hoof $(B-L)$ ~~$(B+L)$~~
 2) $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$
 3) $SU(5)$ $\chi \begin{cases} \rightarrow q q & (B = \frac{2}{3}, L = 0) \\ \rightarrow \bar{q} \bar{l} & (B = \frac{1}{3}, L = -1) \end{cases}$
 L η, π^0

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

2) 't Hooft (B-L) ~~(B+L)~~
 $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$

3) GUT: $SU(5)$ $X \begin{cases} \rightarrow q q (B = \frac{2}{3}, L = 0) \\ \rightarrow \bar{q} \bar{l} (B = \frac{1}{3}, L = -1) \end{cases}$

4) BH evaporation $\eta, \pi^0, M, S, \varphi$

5) Neutrino masses

- 1) ~~P~~
- 2) ~~X, CP~~ ←
- 3) ~~TE~~



$f_i(p, t_f) \neq 0$ $f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$
 $\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$
- 3) GUT: $SU(5)$ $X \begin{cases} \rightarrow q q (B = \frac{2}{3}, L = 0) \\ \rightarrow \bar{q} \bar{l} (B = \frac{1}{3}, L = -1) \end{cases}$
- 4) BH evaporation η, π^0 M, S, φ
- 5) Neutrino masses

$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-11}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

P, C, I

Sakharov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t) d^3x d^3p$$

$$n_B^{(L, N)} = \int d^3p [f_i(p, \vec{x}, t) - \bar{f}_i(\vec{p})]$$

$$f_i(p, t_x) = \bar{f}_i(p, t_x) \Rightarrow n_B = 0$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

$$t_x \left\{ \begin{array}{l} f_i(p, t_x) \xrightarrow{CP} \bar{f}_i(p, t_x) \\ \bar{f}_i(p, t_x) \xrightarrow{CP} f_i(p, t_x) \end{array} \right.$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

1) BII evaporation

η, π^0

M, S, Q

5) Neutrino masses

- 1) $\beta \leftarrow$
- 2) $\phi, \phi^* \leftarrow$
- 3) $\pi \leftarrow$

inflation: $\frac{P}{Q} = \pi$



$$\frac{n_B}{n_Y}$$

$$\left[\frac{n_B}{S} \right] \times 1 \sim 10^{-1}$$

$$\vec{x} \rightarrow -\vec{x}$$

$$\vec{p} \rightarrow -\vec{p}$$

P, C, I

Sakharov:

$$f_i(\vec{x}, \vec{p}, t) d^3\vec{x} d^3\vec{p} = f_i(p, t) d^3x d^3p$$

$$n_B^{(i)} = \int d^3p [f_i(p, t) b_i + \bar{f}_i(p, t) \bar{b}_i]$$

$$f_i(p, t_f) = \bar{f}_i(p, t_f) \Rightarrow n_B = 0$$

$$f_i(p, t_f) \neq \bar{f}_i(p, t_f) \quad n_B(t_f) \neq 0$$

$$t_f \left\{ \begin{array}{l} f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f) : \\ \bar{f}_i(p, t_f) \xrightarrow{CP} f_i(p, t_f) : \end{array} \right.$$

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f) :$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(p, t_f) :$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

4) BH evaporation

η, π^0

M, S, Q

5) Neutrino masses

$$f_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_f)$$

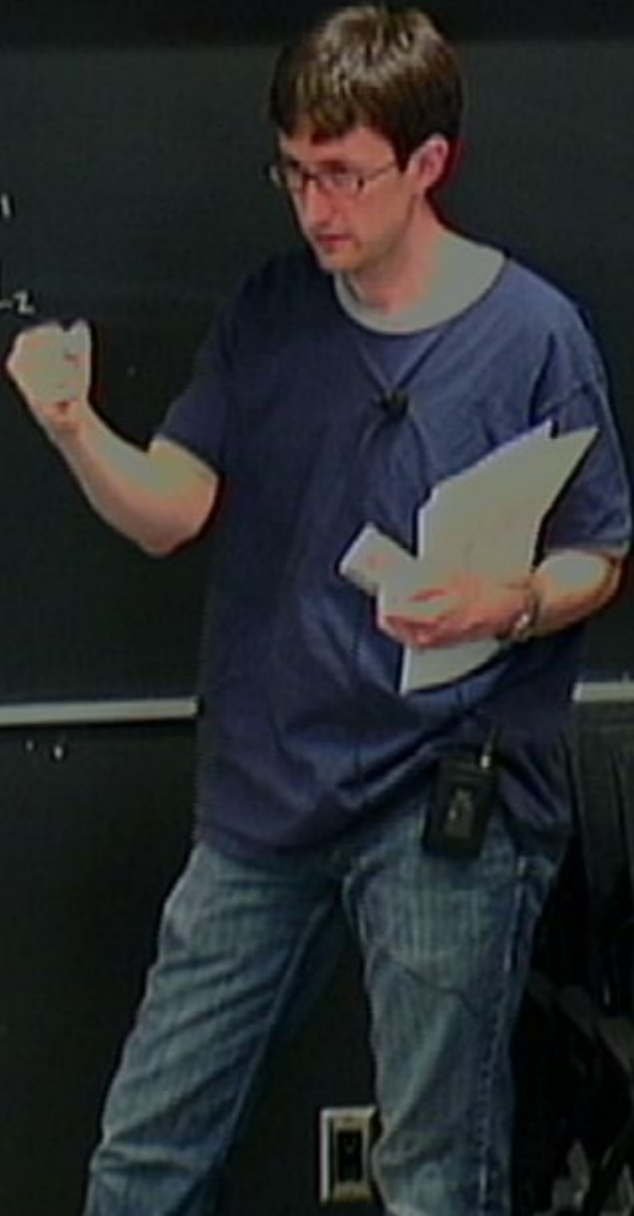
$$\bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi LL$, $\frac{1}{M^2} QQQL$
- 3) GUT: $SU(5)$ $\chi \begin{cases} \rightarrow q q (B = \frac{2}{3}, L = 0) \\ \rightarrow \bar{q} \bar{l} (B = \frac{1}{3}, L = -1) \end{cases}$
- 4) BH evaporation η, π^0 M, S, φ
- 5) Neutrino masses

X → B_1, L_1
X → B_2, L_2

X

$X \rightarrow B_1, L_1$
 $X \rightarrow B_2, L_2$
 $\bar{X} \rightarrow -B_1, -L_1$
 $\bar{X} \rightarrow -B_2, -L_2$



$$\begin{aligned} X &\rightarrow B_1, L_1 (r) \\ &\rightarrow B_2, L_2 (1-r) \\ &\rightarrow -B_1, -L_1 (r) \\ &\rightarrow -B_2, -L_2 (1-r) \end{aligned}$$

$$\begin{aligned} X &\rightarrow B_1, L_1 (r) \\ X &\rightarrow B_2, L_2 (1-r) \\ \bar{X} &\rightarrow -B_1, -L_1 (r) \\ \bar{X} &\rightarrow -B_2, -L_2 (1-r) \\ X &\bar{X} \end{aligned}$$

$$X \rightarrow B_1, L_1 (r)$$

$$\rightarrow B_2, L_2 (1-r)$$

$$-B_1, -L_1 (r)$$

$$-B_2, -L_2 (1-r)$$

$$(X - \bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$

$$X \rightarrow B_1, L_1 (r)$$

$$\rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\rightarrow -B_2, -L_2 (1-r)$$

$$B(X - \bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$
$$= (B_1 - B_2)(r - r)$$

Δx

$$X \rightarrow B_1, L_1 (r)$$

$$X \rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\bar{X} \rightarrow -B_2, -L_2 (1-r)$$

$$B(X - \bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$
$$= (B_1 - B_2)(r - r)$$

$$W = \frac{n_X + n_{\bar{X}}}{S}$$

$$X \rightarrow B_1, L_1 (r)$$

$$\rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (\bar{r})$$

$$\rightarrow -B_2, -L_2 (1-\bar{r})$$

$$B(X - \bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$
$$= (B_1 - B_2)(r - \bar{r})$$

$$B = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - \bar{r})$$

$$X \rightarrow B_1, L_1 (r)$$

$$X \rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (\bar{r})$$

$$\bar{X} \rightarrow -B_2, -L_2 (1-\bar{r})$$

$$D(X - \bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$
$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - \bar{r})$$

$$X \rightarrow B_1, L_1 (r)$$

$$X \rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\bar{X} \rightarrow -B_2, -L_2 (1-r)$$

$$B(X - \bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$
$$= (B_1 - B_2)(r - r)$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - r) = \frac{2}{\delta^*} (B_1 - B_2)(r - r)$$

$$X \rightarrow B_1, L_1 (r)$$

$$\rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\rightarrow -B_2, -L_2 (1-r)$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$
$$= (B_1 - B_2)(r - r)$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - r) = \frac{2}{\delta^*} (B_1 - B_2)(r - r)$$

inflation $\alpha^2 = \epsilon^2 N$

$$\bar{X} \rightarrow -B_1 - L_1 (r)$$

$$\rightarrow -B_2 - L_2 (1-r)$$

$$B(\bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$
$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - \bar{r}) = \frac{2}{\delta^*} (B_1 - B_2)(r - \bar{r})$$

3) $\pi \leftarrow$

inflation: $\frac{B}{a^2 \cdot \infty N}$

$$B(x \bar{x}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r}) \\ = (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{S} = \frac{n_x + n_{\bar{x}}}{S} (B_1 - B_2)(r - \bar{r}) = \frac{2}{\delta^*} (B_1 - B_2)(r - \bar{r})$$

$$X \rightarrow B_1, L_1 (r)$$

$$X \rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\bar{X} \rightarrow -B_2, -L_2 (1-r)$$

$$T < m_k$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$
$$= (B_1 - B_2)(r - r)$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - r) = 0$$

$$X \rightarrow B_1, L_1 (r)$$

$$X \rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\bar{X} \rightarrow -B_2, -L_2 (1-r)$$

$$T < m_k$$

$$\sigma^2 = 1$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$

$$= (B_1 - B_2)(r - r)$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - r) = \frac{\delta^2}{\delta^2}$$

$$X \rightarrow B_1, L_1 (r)$$

$$X \rightarrow B_2, L_2 (1-r)$$

$$\bar{X} \rightarrow -B_1, -L_1 (r)$$

$$\bar{X} \rightarrow -B_2, -L_2 (1-r)$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$
$$= (B_1 - B_2)(r - r)$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - r) = \frac{2(B_1 - B_2)(r - r)}{\delta^*}$$

$$T < m_X$$

$$\Gamma^* = H$$

- X → $B_1, L_1 (r)$
- X → $B_2, L_2 (1-r)$
- \bar{X} → $-B_1, -L_1 (r)$
- \bar{X} → $-B_2, -L_2 (1-r)$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - (-B_1 r - B_2 (1-r))$$

$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}(B_1 - B_2)(r - \bar{r})}{S}$$

$T < m_k$
 $\Gamma'' = H$

$$H^2 = \frac{8\pi G}{3} \rho$$

- X → B₁, L₁ (r)
- X → B₂, L₂ (1-r)
- X̄ → -B₁, -L₁ (r̄)
- X̄ → -B₂, -L₂ (1-r̄)

$$T < m_X$$

$$\Gamma = H$$

$$\propto m_X$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$

$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - \bar{r})$$

$$H = \frac{876}{3} \rho$$

- $X \rightarrow B_1, L_1 (r)$
- $X \rightarrow B_2, L_2 (1-r)$
- $\bar{X} \rightarrow -B_1, -L_1 (r)$
- $\bar{X} \rightarrow -B_2, -L_2 (1-r)$

$$T < m_x$$

$$\Gamma = H$$

$$\propto m_x$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 r - B_2 (1-r)$$

$$= (B_1 - B_2)(r - r)$$

$$\frac{n_B}{S} = \frac{n_X + n_{\bar{X}}}{S} (B_1 - B_2)(r - r) \delta^*$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{9 \cdot T^4}{M_{pl}^2}$$

- X → B₁, L₁ (r)
- X → B₂, L₂ (1-r)
- X̄ → -B₁, -L₁ (r̄)
- X̄ → -B₂, -L₂ (1-r̄)

$$T < m_X$$

$$\Gamma_X = H$$

$$\propto m_X^{-5}$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$

$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{s} = \frac{n_X + n_{\bar{X}}}{s} (B_1 - B_2)(r - \bar{r}) = 0$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{g_{\text{eff}} T^4}{M_{\text{pl}}^2}$$

- X → $B_1, L_1 (r)$
- X → $B_2, L_2 (1-r)$
- \bar{X} → $-B_1, -L_1 (\bar{r})$
- \bar{X} → $-B_2, -L_2 (1-\bar{r})$

$T < m_X$

$$\Gamma_X = H = g_X^{1/2} \frac{T^2}{M_{\text{pl}}} < g_X^{1/2} \frac{m_X}{M_{\text{pl}}}$$

$$m_X > \frac{\alpha_X}{g_X^{1/2}} M_{\text{pl}}$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$

$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{s} = \frac{n_X + n_{\bar{X}}}{s} (B_1 - B_2)(r - \bar{r}) = \frac{3}{8\pi^2} (B_1 - B_2)(r - \bar{r})$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{g_{\text{eff}} T^4}{M_{\text{pl}}^2}$$

- $X \rightarrow B_1, L_1 (v)$
- $X \rightarrow B_2, L_2 (1-v)$
- $\bar{X} \rightarrow -B_1, -L_1 (v)$
- $\bar{X} \rightarrow -B_2$

$$H^2 = g_{\text{eff}} \frac{T^2}{M_{\text{pl}}^2} < g_{\text{eff}} \frac{m_X^2}{M_{\text{pl}}^2}$$

$$m_X > \frac{\alpha_X}{g_{\text{eff}}^{1/2}} M_{\text{pl}}$$

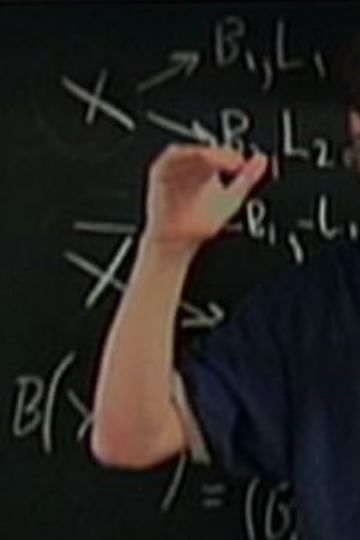
$$B(X\bar{X}) = 1$$

$$3\bar{v} - B_2(1-\bar{v})$$

$$\frac{3(B_1 - B_2)(v - \bar{v})}{g_{\text{eff}}}$$

$$\frac{H^2}{5} =$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{g_* T^4}{M_{pl}^2}$$



$$T < m_x$$

$$\Gamma \approx H = g_*^{1/2} \frac{T^2}{M_{pl}} < g_*^{1/2} \frac{m_x^2}{M_{pl}}$$

$$m_x > \frac{\alpha_x}{g_*^{1/2}} M_{pl}$$

$$\frac{n_B}{s} = \frac{n_x + n}{s} \Rightarrow (B_1 - B_2)(v - \bar{v})$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{g_* T^4}{M_{pl}^2}$$

- X → B₁, L₁ (r)
- X → B₂, L₂ (1-r)
- \bar{X} → -B₁, -L₁ (r)
- \bar{X} → -B₂, -L₂ (1-r)

$T < m_X$

$$\Gamma_X = H = g_X^{1/2} \frac{T^2}{M_{pl}} < g_X^{1/2} \frac{m_X^2}{M_{pl}}$$

$$m_X > \frac{\alpha_X}{g_X^{1/2}} M_{pl}$$

$$B(X\bar{X}) = B_1 r + B_2 (1-r) - B_1 \bar{r} - B_2 (1-\bar{r})$$

$$= (B_1 - B_2)(r - \bar{r})$$

$$\frac{n_B}{s} = \frac{n_X + n_{\bar{X}}}{s} (B_1 - B_2)(r - \bar{r}) = \frac{3}{8\pi^2} (B_1 - B_2)(r - \bar{r})$$

- 1) 1976 't Hooft
- 2) EFT $SU(3) \times SU(2) \times U(1)$
- 3) GUT: $SU(5)$ \times $\begin{cases} \rightarrow 99 & (B = \frac{2}{3}) \\ \rightarrow 9\bar{3} & (B = \frac{1}{3}) \end{cases}$
- 4) BH evaporation γ, π^0, M, S, Q
- 5) Neutrino masses

$$f_i(p, t_f) \xrightarrow{CP} f_i(p, t_i)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_i)$$

$$f_i(p, t_f) \xrightarrow{CP} f_i(p, t_f) : \\ \bar{f}_i(p, t_f) \xrightarrow{CP} f_i(\dots)$$

- ~ $\Gamma \sim T$
- 1) 1976 't Hooft (B-L) ~~(B+L)~~
 - 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi LL$, $\frac{1}{M^2} QQQL$
 - 3) GUT: $SU(5)$ $X \begin{cases} \rightarrow q q (B = \frac{2}{3}, L = 0) \\ \rightarrow q \bar{l} (B = \frac{1}{3}, L = -1) \end{cases}$
 - 4) BH evaporation $\gamma, \pi^0, M, S, \phi$
 - 5) Neutrino masses

$$\begin{aligned}
 f_i(p, t_f) &\xrightarrow{CP} f_i(p, t_i) \\
 \bar{f}_i(p, t_i) &\xrightarrow{CP} \bar{f}_i(p, t_f)
 \end{aligned}$$

$\Gamma \sim T \sim 100 \text{ GeV}$

- 1) 1976 't Hooft (B-L) ~~(B+L)~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi LL$, $\frac{1}{M^2} QQQL$
- 3) GUT: $SU(5)$ $X \begin{cases} \rightarrow q, q & (B = \frac{2}{3}, L = 0) \\ \rightarrow \bar{q}, \bar{l} & (B = \frac{1}{3}, L = -1) \end{cases}$
- 4) BH evaporation $\gamma, \pi^0, M, S, \phi$
- 5) Neutrino masses

$$\begin{aligned}
 f_i(p, t_f) &\xrightarrow{CP} f_i(p, t_i) \\
 \bar{f}_i(p, t_f) &\xrightarrow{CP} \bar{f}_i(p, t_i)
 \end{aligned}$$

$\Gamma \sim T \sim 100 \text{ GeV}$

- 1) 1976 't Hooft $\boxed{(B-L)}$ ~~$(B+L)$~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi L L$, $\frac{1}{M^2} Q Q Q L$
- 3) GUT: $SU(5)$ $X \begin{cases} \rightarrow 99 & (B = \frac{2}{3}, L = 0) \\ \rightarrow 9\bar{3} & (B = \frac{1}{3}, L = -1) \end{cases}$
- 4) BH evaporation $\gamma, \pi^0, M, S, \phi$
- 5) Neutrino masses

$$f_i(p, t_f) \xrightarrow{CP} f_i(p, t_i)$$

$$\bar{f}_i(p, t_f) \xrightarrow{CP} \bar{f}_i(p, t_i)$$

$\Gamma \sim T \sim 100 \text{ GeV}$

- 1) 1976 't Hooft $(B-L)$ ~~$(B+L)$~~
- 2) EFT $SU(3) \times SU(2) \times U(1)$ $\frac{1}{M} \Phi \Phi LL$, $\frac{1}{M^2} QQQL$
- 3) GUT: $SU(5)$ $X \begin{cases} \rightarrow \gamma \gamma & (B = \frac{2}{3}, L = 0) \\ \rightarrow \gamma Z & (B = \frac{1}{3}, L = -1) \end{cases}$
- 4) BH evaporation $\gamma, \pi^0, M, S, \phi$
- 5) Neutrino masses

$(1-\alpha)Y = -L;$
(PIL

1) $\beta \leftarrow$

2) $\alpha, \gamma \leftarrow$

3) $\pi \leftarrow$

inflation: $\frac{B}{\alpha \cdot \pi N}$



$$(B-L)_i = -L_i$$

$$(B+L)$$

- 1) $\beta \leftarrow$
- 2) $\chi, \gamma \leftarrow$
- 3) $\mathcal{I}E \leftarrow$

inflation: $\frac{B}{\alpha^2 \cdot \Omega N}$

$$L_i$$

$$(B+L)_f = (B+L)_i e^{-t\Gamma} \approx 0$$

$$(B-L)_f = (B-L)_i = -L_i$$

$$B_f = -\frac{1}{2}L_i$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{9 \cdot T^4}{M_{pl}^2}$$

- 1) $\beta \leftarrow$
- 2) $\phi, \phi \leftarrow$
- 3) $\cancel{TE} \leftarrow$

$$L_i$$

$$(B+L)_f = (B+L)_i e^{-t\pi} \approx 0$$

$$(B-L)_f = (B-L)_i = -L_i$$

inflation: $\frac{B}{\alpha^2 \cdot \Omega N}$

$$B_f = -\frac{1}{2} L_i$$

$$L_f = \frac{1}{2} L_i$$

$$e^{-\pi} > 0$$

$$8T^4$$

$$H^2 = \frac{8\pi G}{3} \rho = \frac{9 \times T^4}{M_{pl}^2}$$

$$S = \frac{1}{2} (B_1 - B_2)(r - \bar{r})$$

$$H = \frac{1}{2} p^2 - \frac{1}{M} \frac{1}{r}$$

LEPTOGEN: $L_i \neq 0$ R
 $(R-L)_i = -L_i$
 $(R+L$

$$H = \frac{1}{2} p^2 - \frac{M^2}{p}$$

$$\Phi_{LV_R}$$

LEPTOGEN: $L_i \neq 0$
 $(P-L)_i = -L_i$
 $(P+L$

$$H = \frac{1}{2} p^2 - \frac{1}{M_p^2}$$

$$\Phi \nabla_L \nu_R + m \nabla_R \nu_L + h.c.$$

LEPTOGEN: $L_i \neq 0$ $\nu_i \neq 0$
 $(\nu - L)_i = -L_i$
 $(\nu + L)$

$$H = \frac{1}{2} p^2 - \frac{1}{M_{Pl}^2}$$

$$\Phi \nabla_L \nabla_R + m \nabla_R \nabla_R + h.c.$$

LEPTOGEN: $L_i \neq 0$ $\nu_i \neq 0$
 $(\nu - L)_i = -L_i$
 $(\nu + L)$

$$H = \frac{1}{2} p^2 - \frac{M^2}{2p}$$

$$\Phi \bar{\nu}_L \nu_R + \frac{v - v_c}{\Lambda} \overline{M \nu_R \nu_R} + \text{h.c.}$$

$$\nu_R \rightarrow \Phi \nu$$

LEPTOGEN: $L_i \neq 0$ + c
 $(\theta - L)_i = -L_i$
 $(\theta + L)$

$$H = \frac{1}{2} p^2 - \frac{1}{M_{\nu}} p^2$$

$$\Phi \bar{\nu}_L \nu_R + \frac{v - v_c}{M_{\nu}} \bar{\nu}_R \nu_R + h.c.$$

$\nu_R \rightarrow \Phi \nu$
Feynman
diagram

LEPTOGEN: $L_i \neq 0$ $B_i \neq 0$
 $(B-L)_i = -L_i$
 $(B+L)$

$$H = \frac{1}{2} p^2 - \frac{M^2}{M_{pl}}$$

$$\Phi \bar{\nu}_L \nu_R + \frac{v = v_c}{M \nu_R \nu_R} + h.c. \quad m = 0.1 eV$$

~~ψ~~

LEPTOGEN: $L_i \neq 0$
 $(B-L)_i = -L_i$
 $(B-L)$

$$H = \frac{1}{3} \rho^{-1} M_p^2$$

LEPTOGEN $L_i \neq 0$ $B_i \neq 0$
 $(B-L)_i = -L_i$
 $(B+L)$

$\rightarrow -B_1 - L_2$ (1)

$$B(X\bar{X}) = B_1 v$$

$$= (B_1 - B_2) X v$$

$$B_2(1-\bar{v})$$

$$m_x > \frac{\alpha_x}{g_0^{2L}} M_p$$

$$B_2(v-\bar{v})$$

$$\frac{n_B}{S} = \frac{n_x + n_{\bar{x}}}{S} (B_1 - B_2) X$$