Kuno-Lab Mini-Workshop: August 30, 2016

"F" in "LFV" is "Flavor" or "Family" ?

Yoshio Koide

I am a "Flavor Physicist".

I am researching two subjects:

(i) quark and lepton masses and mixings

based on $U(3) \times U(3)'$ family symmetry

and

(ii) family gauge bosons ,

but, I never say "I am a family physicist".

Today, my talk is not a report on my recent researches.

Today, I would like to talk about "flavor" and "family"

how those are different from each other.

If you are a particle physicist, this is well known,

so that you can escape from this room.

Question:

"F" in "LFV" is "Flavor" or "Family?

Formal answer: F = Family

Lepton Family number (*LF*), Lepton number (*L*), $\Delta S = \Delta Q$ (*SQ*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

$\pi^+\pi^+e^-\overline{\nu}_e$	*SQ*	<	1.2		$\times 10^{-8}$	CL=90%	203
$\pi^+\pi^+\mu^-\overline{\nu}_\mu$	*SQ*	<	3.0		$\times 10^{-6}$	CL=95%	151
$\pi^+e^+e^-$	*S1*	(	3.00	±0.09	) $\times 10^{-7}$		227
$\pi^+\mu^+\mu^-$	*S1*	(	9.4	±0.6	) $\times 10^{-8}$	S=2.6	172
$\pi^+\nu\overline{\nu}$	*S1*	(	1.7	±1.1	) $\times 10^{-10}$		227
$\pi^+\pi^0\nu\overline{\nu}$	*S1*	<	4.3		$\times 10^{-5}$	CL=90%	205
$\mu^-\nu e^+e^+$	*LF*	<	2.0		$\times 10^{-8}$	CL=90%	236
$\mu^+\nu_e$	*LF*	[i] <	4		$\times 10^{-3}$	CL=90%	236
$\pi^+\mu^+e^-$	*LF*	<	1.3		$\times 10^{-11}$	CL=90%	214
$\pi^+\mu^-e^+$	*LF*	<	5.2		$\times 10^{-10}$	CL=90%	214
$\pi^-\mu^+e^+$	*L*	<	5.0		$\times 10^{-10}$	CL=90%	214
$\pi^-e^+e^+$	*L*	<	6.4		$\times 10^{-10}$	CL=90%	227
$\pi^-\mu^+\mu^+$	*L*	[i] <	1.1		$\times 10^{-9}$	CL=90%	172
$\mu^+\overline{\nu}_e$	*L*	[i] <	3.3		$\times 10^{-3}$	CL=90%	236
$\pi^0e^+\overline{\nu}_e$	*L*	<	3		$\times 10^{-3}$	CL=90%	228

PDG 2012

At least,

since 2004

Terminology used in PDG is usually regarded as standard.

Examples of usage

- Old SU(3) flavor symmetry based on (u, d, s)

- At present, we know quarks

u	c	t
d	s	b

How many families? The number of families is 3.

How many flavors? The number of flavors is 6.

Nevertheless, most Japanese read "LFV" as "Lepton Flavor Violation"

However, we cannot declare that it is wrong usage.

We know that the weak interactions are described by $SU(2)_L$ gauge theory

$SU(2)_L$ doublets:

$$\ell_e = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L, \quad \ell_\mu = \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L, \quad \ell_\tau = \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L,$$

We have to assign the same quantum number for two particles inside each doublet.

Therefore, for both cases F=Flavor and F=Family,

we can assign LF-numbers

F-number	N_e	N_μ	N_τ
$l_e = (\nu_e, e^-)_L$	1	0	0
$l_\mu = (\nu_\mu, \mu^-)_L$	0	1	0
$l_\tau = (\nu_\tau, \tau^-)_L$	0	0	1

To the contrast, for the right-handed leptons,

the assignment may be different: for example,

F = Family,	N_e
ν_{eR}	1
e^-_R	1

F = Flavor,	$N_{R\nu}$	N_{Re}
ν_{eR}	1	0
e^-_R	0	1

and so on

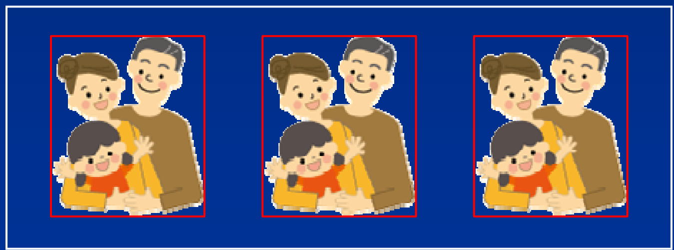
However, I have never seen such an assignment of the right-handed side, because, we know that, in the renormalized field theory, total charge $Q = \sum Q_L - \sum Q_R$ has to be always zero.

Summary

- As far as the lepton number assignment are concerned, "family" number and "flavor" number are practically the same.
- However, the concepts are completely different!
- It is better to read LFV as "lepton family number violation", because now F=family is common sense in the physics community.

Supplement

Family versus Generation



How different between Generation and Family?

Generations（世代）

Structures are completely different each other

1st, 2nd, ・・・:

The order is essential.

Never take concept of Symmetry

Families （家族）

Each state is originally on an equal footing.

By some reason, the democracy was broken.

We may consider "Symmetry"

In general, family assignment can be different from generation assignment

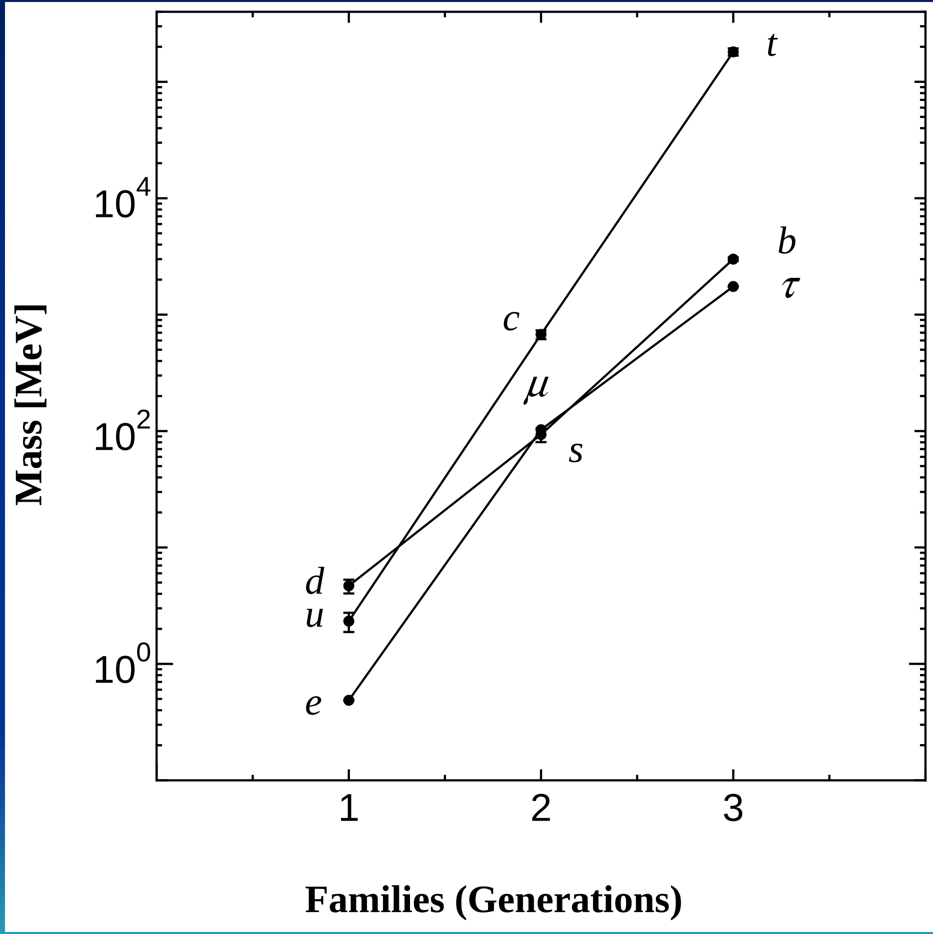
e.g. we can take a family assignment

$$(e_1, e_2, e_3) = (e^-, \mu^-, \tau^-) \qquad (d_1, d_2, d_3) = (b, d, s)$$

YK, Phys.Lett. B736, 499 (2014)

Why we do not consider Family Symmetry?

Quark and lepton masses



Such the hierarchical structure cannot understand by "Symmetry", because the conventional prescription was "symmetry + a small symmetry breaking term,".

We are forced to give up to take the approach of symmetry.

Masses and Mixings

In the standard model (SM), masses and mixings are generated by Yukawa coupling constants:

$$H_Y = (\bar{q}_L)^i (Y_u)_i{}^j (u_R)_j H_u + (\bar{q}_L)^i (Y_d)_i{}^j (d_R)_j H_d$$

where $q_L = (u_L, d_L)$ is $SU(2)_L$ doublet

Besides, when we want to consider a symmetry, Yukawa coupling constants break symmetry explicitly.

The Yukawa coupling constants Y_f are fundamental constants and we cannot explain those by any theory, at least, in the framework of SM .

However, we know Higgs mechanism!

We can consider a Higgs-like mechanism.

We consider that Yukawa coupling constants are not "constants", but effective constants" which are generated by Vacuum Expectation Values (VEV) of hypothetical scalars ("Yukawaons").

$$(Y_f^{eff})_i{}^j = \frac{y_f}{\Lambda} \langle Y_f \rangle_i{}^j \qquad (f = u, d, \nu, e)$$

Yukawaon model

YK, Phys.Rev. D79, 033009 (2009); Phys.Lett. B 680, 76 (2009).

Therefore, nowadays, it has been possible to consider quark and lepton masses and mixings on the bases of "symmetry".

I have to stop my talk,

because I am afraid of going far into excessive theoretical details.

See you again!