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flip tanedo

Pop Sci: Higgs gives everything mass!

[False]   we know that most of the 'ordinary' mass in the universe comes from QCD binding energy!!

BUT: Higgs gives up & down quark masses.
$M_d > M_u \Rightarrow M_n > M_p \Rightarrow$ ATOMS ARE STABLE!

↳ indeed, $M_n - M_p \sim M_d - M_u$

TODAY: what the Higgs is REALLY good for.
↳ "breaking" the ELECTROWEAK force
... will happen to give mass
so we'll have to figure out
what that means.

btw: one more lecture next wk : intro to Beyond the Standard Model!

Higgs rules

$--\overset{h}{-}--$ SPIN - 0
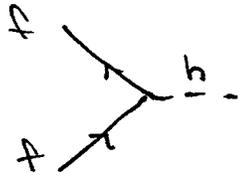
f $\overset{h}{\diagdown}$ f = massive fermion : u, d, ℓ, (ν)
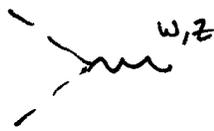
W,Z ← I forgot this last time.

W,Z W,Z
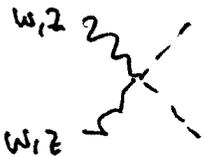
§ the Higgs vev : $---X$

ANALOGY: WE ARE fish SWIMMING IN THE HIGGS VEV
HIGGS **PARTICLE** IS AN EXCITATION (WAVE)

WATER

don't take this too seriously!

ALSO: See CERN cartoon about Higgs as a socialite party ... New: after this talk, understand the limits of that analogy!

NOW LET'S TALK ABOUT ELECTROWEAK FORCE

"Unified" QED + WEAK.
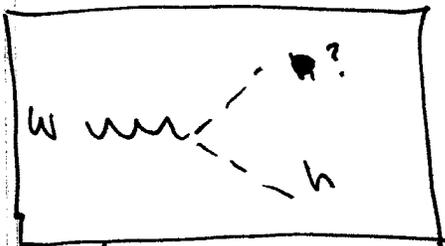
WE KNOW THAT THE ω talks to pairs of particles:

$$\begin{pmatrix} \nu \\ e \end{pmatrix} \, , \quad \begin{pmatrix} u \\ d \end{pmatrix}$$

SO WHAT ABOUT THE HIGGS?
EVIDENTLY IT SHOULD COME IN A PACKAGED PAIR.

$$\begin{pmatrix} h(x) + iH(x) + v \\ g(x) + iG(x) \end{pmatrix}$$

written the FIELDS

decomposed into
Re + i Im
[something we can do for spin-0]

VACUUM EXPECT. (VEV)

HOLD ON TO THIS PICTURE!

Why is there a Higgs vev?

NORMAL FIELD

DEFAULT VALUE
$\phi(x) = 0$

PARTICLE EXCITATION
OF THE fixed ϕ
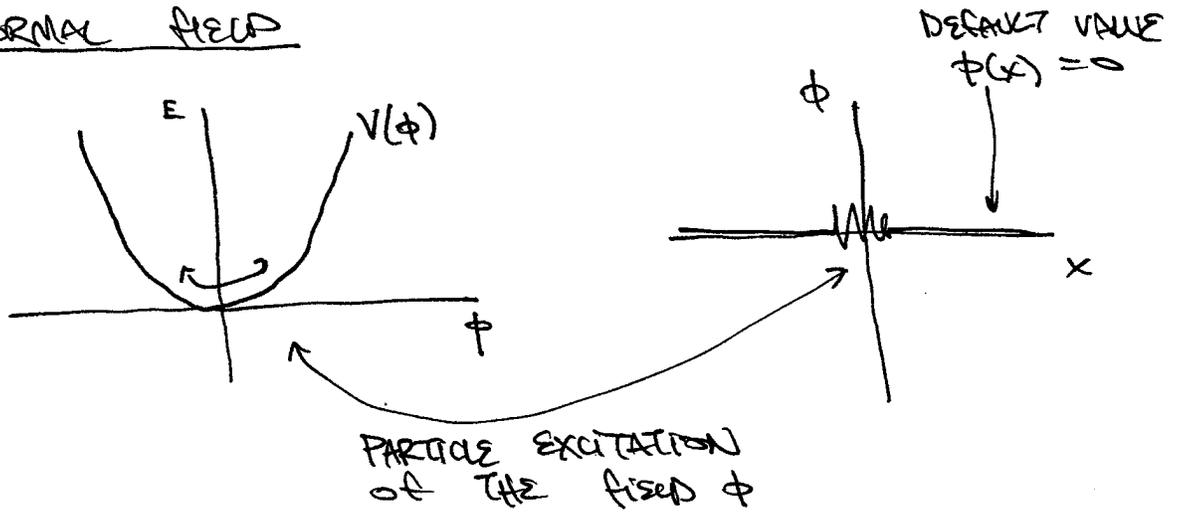
Higgs (simple version; full version later)

default
$h(x) = v$
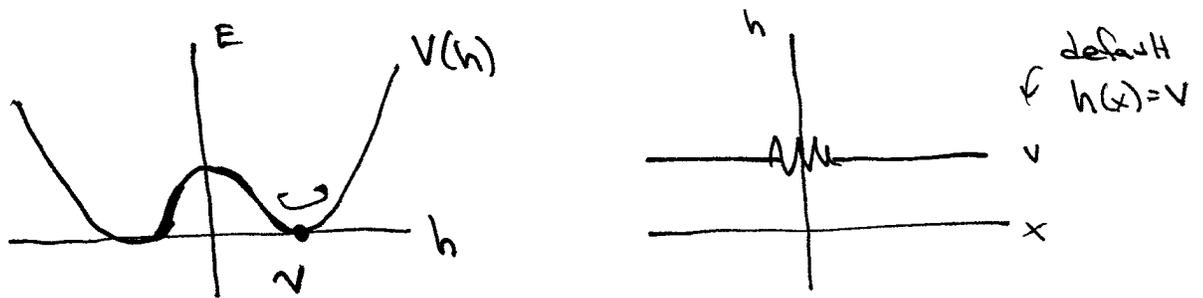
RECALL: the vev can create/ destroy virtual higgses!

<u>Note</u>: this "breaks" the 2-charge "ELECTROWEAK" force ... DON'T NEED TO KNOW THE DETAILS, BUT CAN SEE IT:

$$\left(\begin{array}{c} ... \quad + v \nearrow \\ ... \end{array} \right) \text{always on}$$

0 by default

cf. QED near a charged cat.

− charge is turned on.

$e^+ \quad e^-$
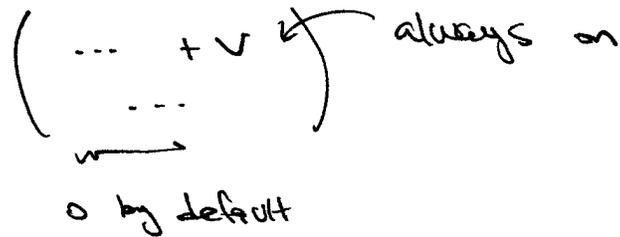
e^+ & e^- behave differently!

now one of the EW charges is turned on! "UPPER" CHARGED THINGS BEHAVE DIFFERENTLY FROM "LOWER" CHARGED THINGS!

eg. spontaneously magnetized materials.

no net B field

lower ENERGY

Magnetized!

MASS $\longrightarrow$ ① $\longrightarrow \longrightarrow$

② $\sim\!\!\!\sim\!\!\!\sim$ $\sim\!\!\!\sim\!- -\sim\!\!\!\sim$
       ✗   ✗   ✗   ✗
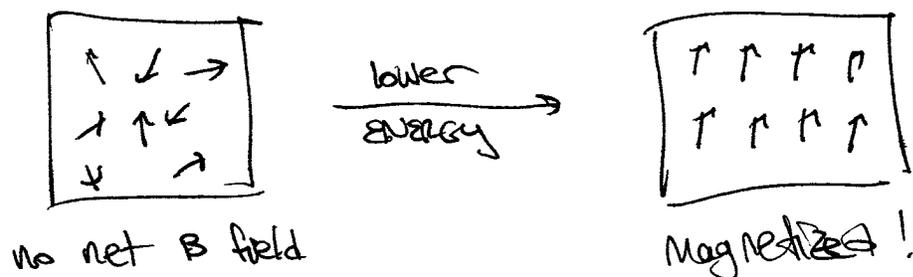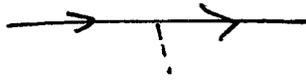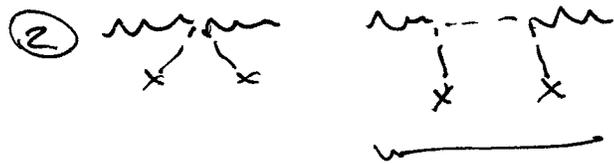
looks like mixing!

① FERMIONS : SPIN ½
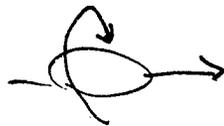
"Helicity"

LAST TIME :   LH   MASSLESS.

We can _never_ make this RH
by going to some frame.

MASS $\longleftrightarrow$ ability to swap between
              LH ξ RH spinning fermions

BUT IF MASSLESS (OR EFFECTIVELY SO), COULD IMAGINE
_ALL_ NEUTRINOS ARE LH. (this is a
consistent theory)

      indeed, very close to reality!

SO HERE'S THE DEAL: forget everything about the SM.
ASSUME EVERYTHING IS MASSLESS.
↳ eg in the EARLY UNIVERSE WHERE
MASSES ARE NEGLIGIBLE w/t TEMP.

then: I have 2 DIFFERENT PARTICLES:

$e_L = $ (LH) $\rightarrow$ $\xi = -1$ | $e_R = $ [RH] $\rightarrow$ $\xi = -1$

_____ | _____

(this interacts w/ W boson) | I cannot talk to w!

!?! (1960s) → SM breaks parity

completely different!
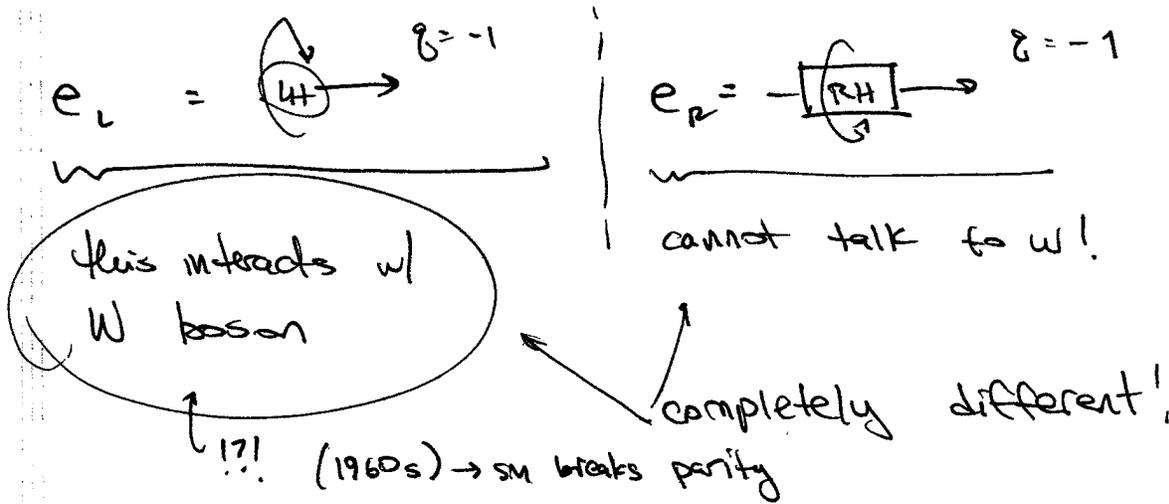
what about anti-partners?

ANTIPARTICLE : charge conjugate + parity reversal [C / P]

[this is the REAL definition of antiparticle]

why: CPT is good → CP = T

e⁻ e⁻ e⁻ →   ←—T—→   ← e⁻ e⁻ e⁻
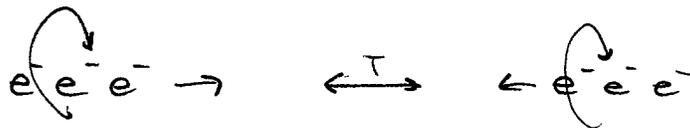
CURRENT FLIPS SIGN
EA PARTICLE HAS OPP SPIN

(8) :

L $q = -$

R $q = -$

$\uparrow$ CP

anti L $q = +$

"LH e^+"

anti R $q = +$

"RH e^+"
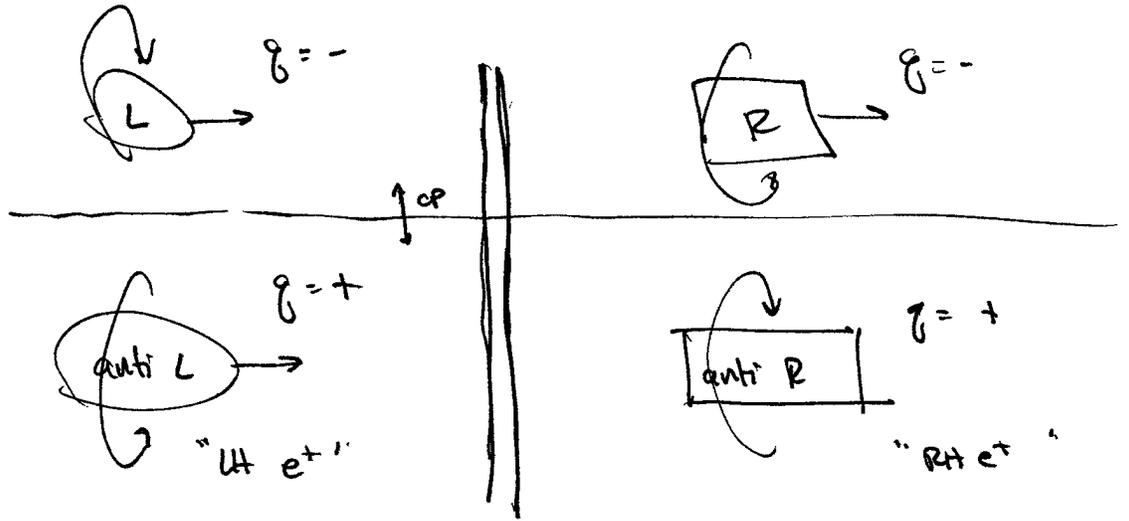
everything massless

Higgs: GLUES $\xrightarrow{\;L\;}$ together w/ $\xrightarrow{\;R\;}$

L   R

h
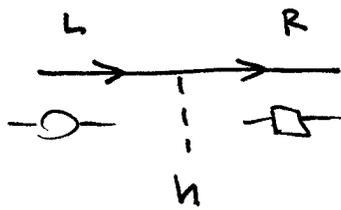
convince yourself of
this by angular
momentum conservation!

eg. $\dot{j} = 0$

spin-0

L

R

anti R
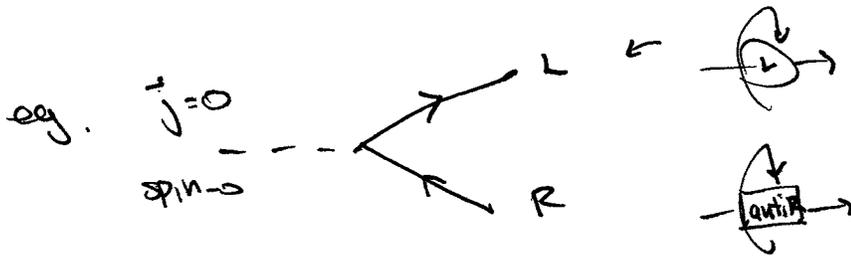
in lab frame: $\times \frac{v}{c}$ ✓

do the __actual__ SM matter content!

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad + \quad u_R \quad \longrightarrow \quad u$$
$$\qquad\qquad\quad + \quad d_R \quad \longrightarrow \quad d$$

$$\begin{pmatrix} \nu_{e_L} \\ e_L \end{pmatrix} \qquad\quad ? \quad \dashrightarrow \quad \nu$$
$$\qquad\qquad + \quad e_R \quad \longrightarrow \quad e$$

talks to W
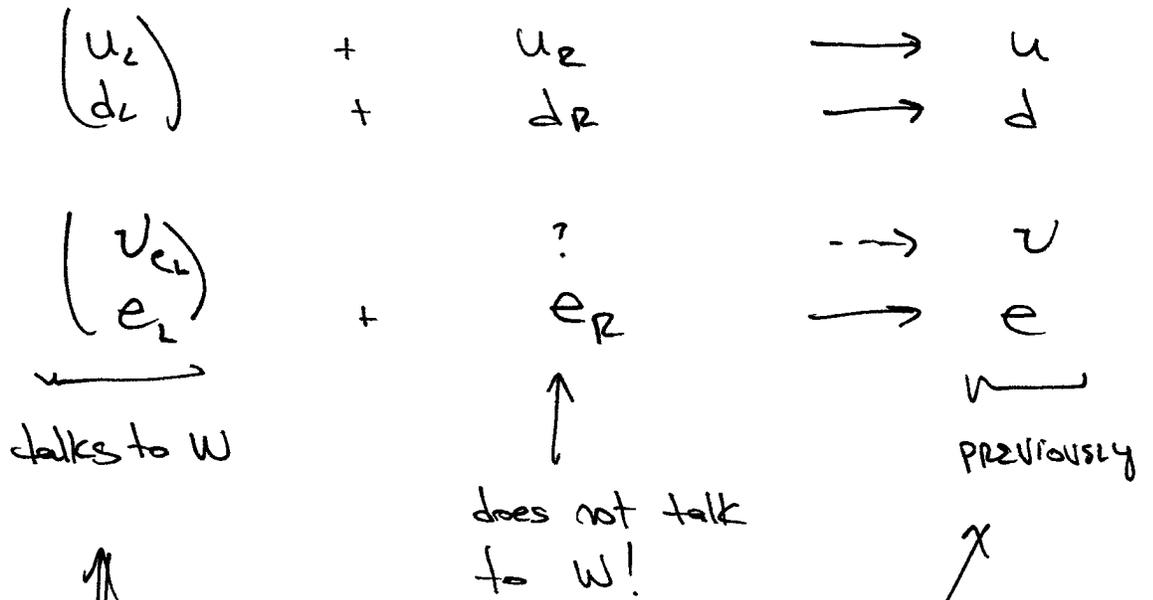
important:
__DIFFERENT__
particles!

does not talk
to W!

talk to W
only through LH
components !!

PREVIOUSLY

note: AMOUT of MIXING DEPENDS ON FRAME

$$\sim \left(\frac{\nu}{E}\right) \qquad \text{AS EXPECTED!}$$

② <u>Gauge bosons</u>

$\gamma \longleftrightarrow$ EM field $\longrightarrow$ LH, RH CIRC. POLARIZATION
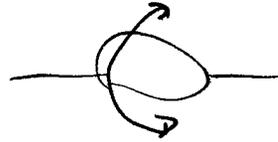
MASSIVE SPIN-1 PARTICLE :
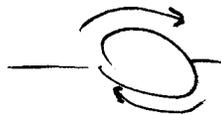
<u>MASS</u>: the ability to go into this state

(can you see why this violates relativity if a massless particle could do this?)

[REMARK: "QUANTUM" IN QM REFERS TO THINGS LIKE SPIN: DISCRETE VALUES: $(-\frac{1}{2}, \frac{1}{2})$, $(-1, 0, 1)$, etc.]

<u>BUT</u>: Relativity relates V & $\vec{A}$
just imagine a current of e^- in rest frame.

PACKAGE INTO 4-component $A_\mu = (V, \vec{A})$
eg "BOOSTS" ARE ROTATIONS BTWN V & $\vec{A}$

then GAUGE BOSON <u>POLARIZ</u> described by excitations of A_μ ⤵ $(\bullet, \bullet, -, -)$

eg: LH RH LONG. ???

GAUGE REDUNDANCY!
↓
"GR"
ORIGIN OF FORCE

Q: massive Z, W?

→ EW thy: start out massless

need extra "type of excitation"
for each of W^+, W^-, Z
to describe this longitudinal
mode.

$$\rightarrow \begin{pmatrix} h(x) + v & +i H^\circ(z) \\ \underbrace{g(x)} & + i G^\circ(z) \end{pmatrix}$$

$$G^+(z) \quad \& \quad G^-(z)$$

so:

$W^\pm \qquad\qquad G^\pm \qquad\qquad W^\pm$
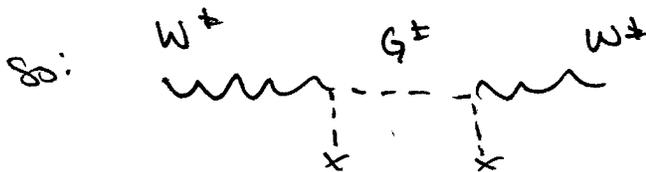
mixing w/ extra Higgs guys:

GOLDSTONE BOSONS.

What are these "Goldstones"?

magnet :

→

vs.
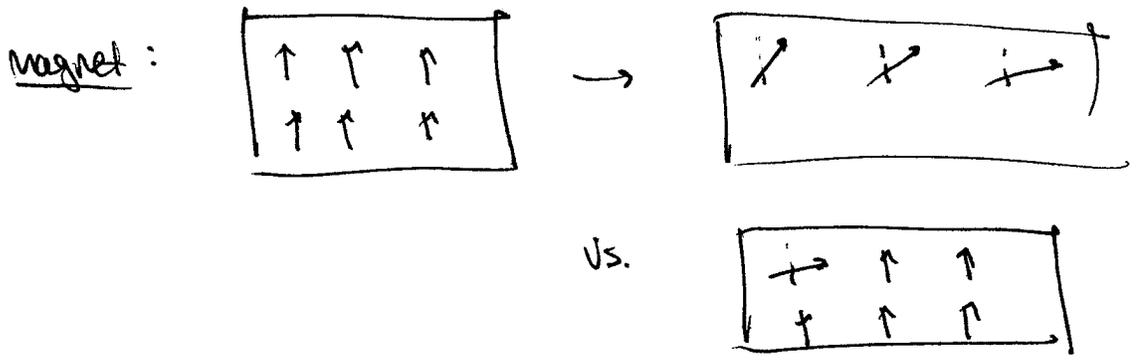
EXCITATIONS of THE HIGGS WHICH DON'T COST ENERGY!
(MASSLESS)
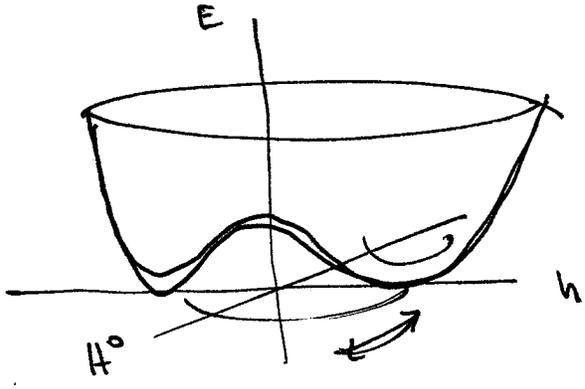
IN FACT :

WE START OUT w/ $B, W^{1,2,3}, H^0, G^{\pm}, h$

$$B + W^3 = \gamma \quad (\text{LH} + \text{RH})$$
$$(W^1 + i W^2) + G^+ = W^+$$
$$(W^1 - i W^2) + G^- = W^- \quad \Big\} \quad (\text{LH} + \text{RH} + \text{LONG.})$$
$$B - W^3 + H^0 = Z$$

$$h \quad \longrightarrow \quad h \quad w/ \text{ vev}$$

the SM fields are all mixtures!

"CHANGE IN BASIS"

HEURISTICALLY :

$$\equiv \quad \longrightarrow \quad e, \text{ MASSIVE}$$