Standard Model and beyond

in Colombia and in the World

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XXIX vigesimonoveno CONGRESO NACIONAL DE FÍSICA

Focus on
Dark matter and neutrinos
In collaboration with
HEP Community in Colombia

Least Action

SO(3) **scalar product**

$$L = \frac{1}{2} m v^2 - V(|\boldsymbol{r}|) = \frac{1}{2} m \boldsymbol{v} \cdot \boldsymbol{v} - V(|\boldsymbol{r}|)$$

SO(3) scalar product

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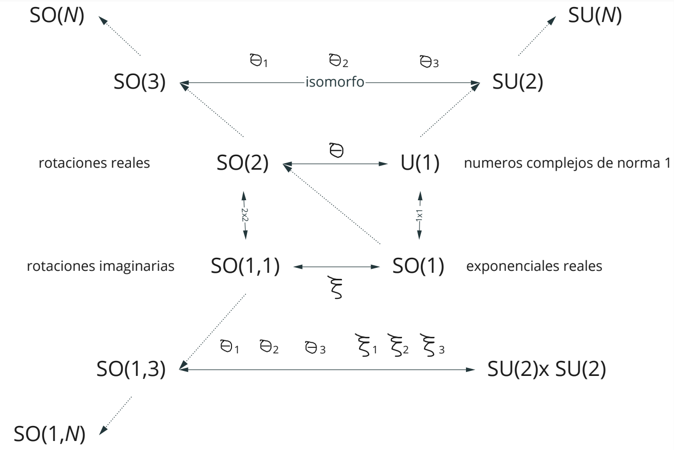
Lie groups



$$U = \exp\left(i \sum_j T_j \theta^j\right), \tag{1}$$

where θ^j are the parameters of the transformation and T_j are the generators.

SO(1)

Consider the 1×1

$$K = -i\,, \tag{2}$$

which generates an element of dilaton group , SO(1), $R(\xi)$

$$\lambda(\xi) = \mathrm{e}^{\xi}\,, \tag{3}$$

which are just the group of the real exponentials. Such a number can be transformed as

$$x \to x' = \mathrm{e}^{\xi}\, x\,, \tag{4}$$

that corresponds to a boost by e^{ξ}. We can define the invariant scalar product just as the division of real numbers, such that

$$x \cdot y \to x' \cdot y' \equiv \frac{x'}{y'} = \frac{\mathrm{e}^{\xi}\, x}{\mathrm{e}^{\xi}\, y} = \frac{x}{y} = x \cdot y\,. \tag{5}$$

SO(1, 1)

Queremos obtener una representación 2×2 del álgebra

$$K = \begin{pmatrix} 0 & -i \\ -i & 0 \end{pmatrix} \to K^2 = -\mathbf{1}\,, \tag{6}$$

que genera un elemento del grupo SO(1, 1) con *parámetro* ξ

$$\Lambda = \exp\left(i\xi K\right) = \begin{pmatrix} \cosh\xi & \sinh\xi \\ \sinh\xi & \cosh\xi \end{pmatrix}\,,\,. \tag{7}$$

La transformación de una coordenada temporaloide y otra espacialoide ($c = 1$)

$$\begin{pmatrix} t \\ x \end{pmatrix} = \begin{pmatrix} x^0 \\ x^1 \end{pmatrix} \to \begin{pmatrix} x'^0 \\ x'^1 \end{pmatrix} = \begin{pmatrix} \cosh\xi & \sinh\xi \\ \sinh\xi & \cosh\xi \end{pmatrix} \begin{pmatrix} x^0 \\ x^1 \end{pmatrix}$$

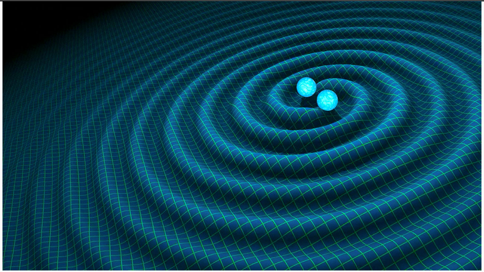
$$x'^\mu = \Lambda^\mu{}_\nu x^\nu\,, \qquad \mu = 0, 1\,.$$

$$\cosh \xi = \gamma = \frac{1}{\sqrt{1 - v^2}}$$

Special: parameter ξ or v is constant, e.g, inertial system invariance: *Global* conservation of E and $\boldsymbol{p}$ (still action at a distance!)

General: parameter $\xi(t, \boldsymbol{x})$ or $v(t, \boldsymbol{x})$ is constant, e.g, accelerated system invariance: *Local* conservation of E and $\boldsymbol{p}$

Inestability of binary particle systems

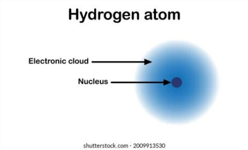


Gravitational wave discovery by LIGO

credits: science.org

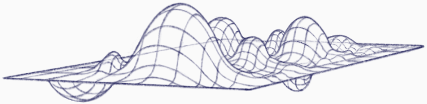
Noether's paradigm $\rightarrow$ Lagrangian formulation of classical field theory

U(1): **From special θ to general $\theta(t, \boldsymbol{x})$**

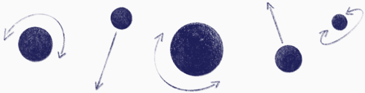


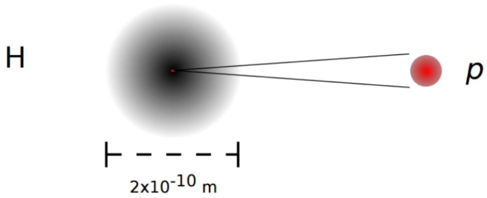
What is a ~~particle~~ *wavicle*? `https://www.quantamagazine.org/what-is-a-particle-20201112/`

Is a "Quantum Excitation of a Field"



Is a "Irreducible Representation of a Group"



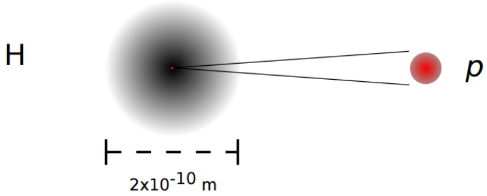

H
p
2x10-10 m

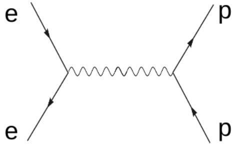
Interacción → Fuerza = Δ**p**/Δt

Introducción

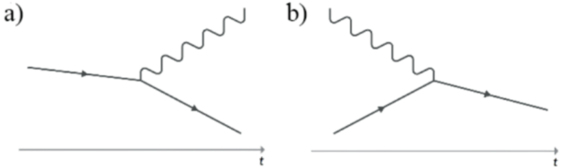
Campos de materia

Campos de radiación





doi:10.1088/1742-6596/1287/1/012045



Emisión absorción

Interacción → Fuerza = $\Delta \mathbf{p}/\Delta t$

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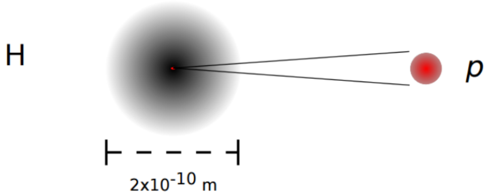

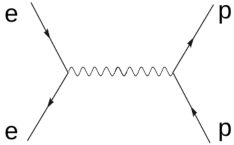

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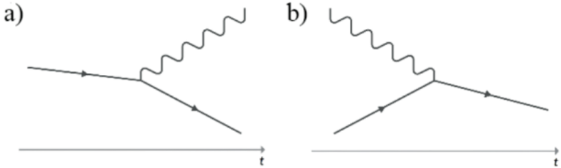
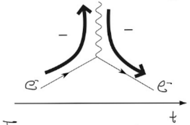


Emisión absorción

$$e^{-} \rightarrow e^{-iEt}$$

$$e^{+} \rightarrow e^{-iE(-t)}$$

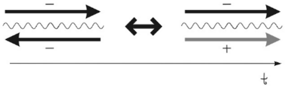
Single charge

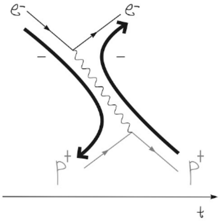


Fuerza $\dfrac{\Delta \vec{p}}{\Delta t} \neq 0$

$(e^-)^* = e^+$

fotón neutro





Under a general Lorentz transformation we have for a pure upperscript 4-vector

$$A^{\mu}(x) \to A'^{\mu}(x) = \Lambda^{\mu}{}_{\nu} A^{\nu}(\Lambda^{-1}x), \tag{8}$$

where $\mu = 0, 1, 2, 3$. A pure underscript 4-vector is

$$\partial_{\mu} = \frac{\partial}{\partial x^{\mu}} = \left(\frac{\partial}{\partial t}, \frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right) = (\partial_0, \boldsymbol{\nabla}). \tag{9}$$

From $x'^{\mu} = \Lambda^{\mu}{}_{\nu} x^{\nu}$

$$\frac{1}{x'^{\mu}} = \left(\Lambda^{-1}\right)^{\nu}{}_{\mu} \frac{1}{x^{\nu}}\,, \tag{10}$$

the tranformation properties for a $\partial_{\mu} = \partial/\partial x^{\mu}$, are

$$\partial'_{\mu} = \partial_{\nu} \left(\Lambda^{-1}\right)^{\nu}{}_{\mu}\,. \tag{11}$$

In this way, the invariant scalar product between the 4-vector field and the four-gradient is just

$$\partial_{\mu} A^{\mu} \to \partial'_{\mu} A'^{\mu} = \partial_{\mu} A^{\mu}\,. \tag{12}$$

Photon: Representation of the Poincaré Groupwhich transform as a vector under $\mathrm{SO}(1,3)$

Name	Symbol	$\mathrm{SO}(1,3)$
Photon	A^μ	$\Lambda^\mu{}_\nu A^\nu$
4-gradient	∂_μ	$\partial_\nu \left(\Lambda^{-1}\right)^\nu{}_\mu$

Table 1: Scalar products: $\partial_\mu A^\mu\,, \quad A^\nu A_\nu\,, \quad \partial_\mu \partial^\mu$

Name	Symbol	SU(N)
scalar N-plet	Ψ	$U\Psi$
scalar anti-N-plet	$\Psi^\dagger$	$\Psi^\dagger U^\dagger$

Table 2: Scalar products: $\Psi^\dagger\Psi$

Photon: $\hat{\boldsymbol{p}} \oplus \mathrm{SO}(1,3) = i\partial^\mu \oplus \mathrm{SO}(1,3) \to i\,D^\mu \oplus \mathrm{SO}(1,3)$

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Table 2: Scalar products: $\Psi^\dagger \Psi$

Name	Symbol	$\mathrm{SL}(2,C)$	$U(1)_Q$
e_L: electron left	ξ_α	${S_\alpha}^\beta \xi_\beta$	$e^{i\theta}\xi_\alpha$
$(e_L)^\dagger$: positron right	$(\xi_\alpha)^\dagger = \xi^\dagger_{\dot\alpha}$	$\xi^\dagger_{\dot\beta}{\left[S^\dagger\right]^{\dot\beta}}_{\dot\alpha}$	$\xi^\dagger_{\dot\alpha}e^{-i\theta}$
e_R: electron right	$(\eta^\alpha)^\dagger = \eta^{\dagger\,\dot\alpha}$	${\left[\left(S^{-1}\right)^\dagger\right]^{\dot\alpha}}_{\dot\beta}\eta^{\dagger\,\dot\beta}$	$e^{i\theta}\eta^{\dagger\,\dot\alpha}$
$(e_R)^\dagger$: positron left	η^α	$\eta^\beta{\left[S^{-1}\right]_\beta}^\alpha$	$e^{-i\theta}\eta^\alpha$

Table 3: electron left: $\mathrm{SL}(2,C)\times U(1)$ inferior and positron left: $\mathrm{SL}(2,C)\times U(1)$ superior

Scalar products

- ~~U(1)~~ Majorana scalars: $\xi^\alpha\xi_\alpha + \xi^\dagger_{\dot\alpha}\xi^{\dagger\dot\alpha}$, $\eta^\alpha\eta_\alpha + \eta^\dagger_{\dot\alpha}\eta^{\dagger\dot\alpha}$.
- Dirac scalar: $\eta^\alpha\xi_\alpha + \xi^\dagger_{\dot\alpha}\eta^{\dagger\,\dot\alpha}$.
- Tensor under subgroup $\mathrm{SL}(2,C)$ but vector under $\mathrm{SO}(1,3)$: ${S^{\dagger\dot\alpha}}_{\dot\beta}\overline{\sigma}^{\mu\,\dot\beta\beta}{S_\beta}^\alpha = {\Lambda^\mu}_\nu\overline{\sigma}^{\nu\,\dot\alpha\alpha}$

$$\sigma^0 = \mathbb{1}\,,\qquad \overline{\sigma}^\mu = (\sigma^0, -\boldsymbol{\sigma}),\qquad \sigma^\mu = (\sigma^0, \boldsymbol{\sigma}).$$

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Table 4: electron left: SL(2, C) $\times$ $U(1)$ inferior and positron left: SL(2, C) $\times$ $U(1)$ superior

General theory: QED $\rightarrow D_\mu = i\partial_\mu - ieA_\mu$, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$

$$\xi^\alpha \rightarrow \xi'^\alpha = e^{i\theta(x)}\xi^\alpha \qquad \eta_\alpha \rightarrow \eta'_\alpha = e^{-i\theta(x)}\eta_\alpha$$

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$$\mathcal{L} = i\xi^\dagger_{\dot\alpha}\bar\sigma^{\mu\,\dot\alpha\alpha}D_\mu\xi_\alpha + i\eta^\alpha\sigma^\mu_{\alpha\dot\alpha}D_\mu\eta^{\dagger\,\dot\alpha} - m\left(\eta^\alpha\xi_\alpha + \xi^\dagger_{\dot\alpha}\eta^{\dagger\,\dot\alpha}\right) - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}$$

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$$\mathcal{L} = i\bar\psi\gamma^\mu D_\mu\psi - m\bar\psi\psi - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}\,.$$

Dirac spinor

$$\psi = \begin{pmatrix} e_L \\ e_R \end{pmatrix}$$

$$\gamma^\mu = \begin{pmatrix} 0 & \sigma^\mu \\ \bar\sigma^\mu & 0 \end{pmatrix}$$

$$\bar\psi = \psi^\dagger\gamma^0\,.$$

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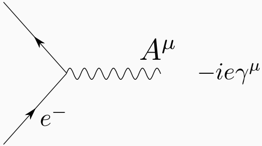

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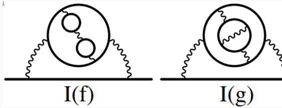
$$\mathcal{L} = i\bar\psi\gamma^\mu D_\mu\psi - m\bar\psi\psi - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} \,. \to e\bar\psi\gamma^\mu\psi\, A_\mu$$

Dirac spinor

non-bare

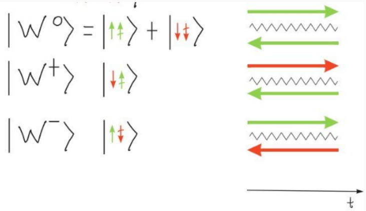


$SU(2)_L \quad \rightarrow D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu$: 17 years later... (stages of grief → 1967)

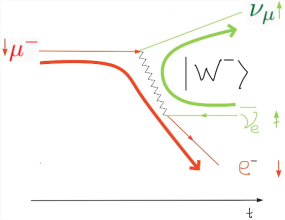
Not mass, not charge

Field	Lorentz	$SU(2)_L$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**

Denial



$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu}$$

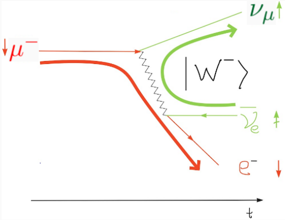


$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 17 years later... (stages of grief → 1967)

Not mass, hypercharge,

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**	$-1/2$

$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$



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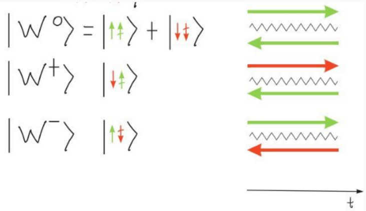
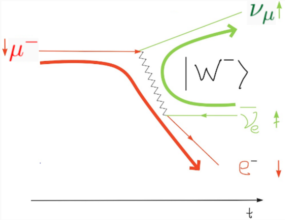


$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 17 years later... (stages of grief → 1967)

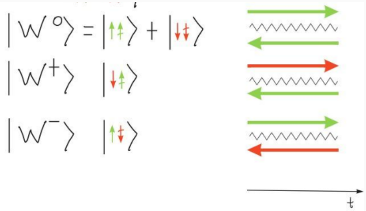
Not mass, hypercharge, not Dirac

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**	$-1/2$
$(e_R)^\dagger$	η^α	**1**	-1

$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R$$



Denial

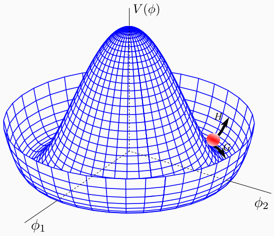


$SU(2)_L \times U(1)_Y \to D_\mu = \mathbf{1}\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 17 years later... (stages of grief → 1967)

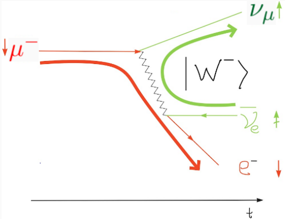
Higgs mechanism: tachyonic mass $\mu^2 < 0$, and condensate

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**	$-1/2$
$(e_R)^\dagger$	η^α	**1**	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x)+v}{\sqrt{2}}\right] \exp\left[i\frac{\tau^i}{2} G_i(x)\right]$	-	**2**	$1/2$

Contempt



$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda \left(\Phi^\dagger \Phi\right.$$



$\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \to D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 17 years later... (stages of grief → 1967)

Higgs mechanism: tachyonic mass $\mu^2 < 0$, and condensate

Field	Lorentz	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**	$-1/2$
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$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x)+v}{\sqrt{2}}\right] \exp\left[i\frac{\tau^i}{2} G_i(x)\right]$	-	**2**	$1/2$

Contempt

$$\begin{pmatrix} W^3_\mu \\ B_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} Z_\mu \\ A_\mu \end{pmatrix},$$

$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi$$

$$\Phi \to \Phi' = \exp\left[i\frac{\tau^i}{2}\theta_i(x)\right] \Phi = \frac{1}{\sqrt{2}}[H(x) + v]$$

$$\mathcal{L} = i\bar{\psi}\gamma^\mu \partial\psi - m_e \bar{\psi}\psi - i(\nu_L)^\dagger \bar{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2}\partial^\mu H \partial_\mu H + \frac{e}{\cos\theta_W \sin\theta_W} \overline{\nu_L}\nu_L Z_\mu + \cdots$$

$$-\frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2}\right) + \left(m_W^2 W^{\mu -} W^+_\mu + \frac{1}{2} m_Z^2 Z^\mu Z_\mu\right)\left(1 + 2\frac{H}{v} + \frac{H^2}{v^2}\right) + \frac{m_e}{v}\bar{\psi}\psi H$$

$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 21 years later... (stages of grief $\to$ 1971)

Z and W phenomenology and discovery

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	$\mathbf{2}$	$-1/2$
$(e_R)^\dagger$	η^α	$\mathbf{1}$	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x)+v}{\sqrt{2}}\right] \exp\left[i\frac{\tau^i}{2} G_i(x)\right]$	-	$\mathbf{2}$	$1/2$

Bargaining

$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi$$

$$\Phi \to \Phi' = \exp\left[i\frac{\tau^i}{2}\theta_i(x)\right] \Phi = \frac{1}{\sqrt{2}}[H(x) + v]$$

$$\mathcal{L} = i\overline{\psi}\gamma^\mu \partial\psi - m_e \overline{\psi}\psi - i(\nu_L)^\dagger \overline{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2}\partial^\mu H \partial_\mu H + \frac{e}{\cos\theta_W \sin\theta_W} \overline{\nu_L} \nu_L Z_\mu + \cdots$$

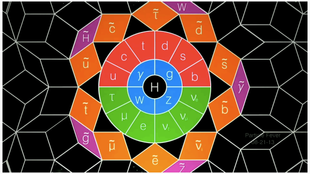
$$- \frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2}\right) + \left(m_W^2 W^{\mu -} W^+_\mu + \frac{1}{2} m_Z^2 Z^\mu Z_\mu\right)\left(1 + 2\frac{H}{v} + \frac{H^2}{v^2}\right) + \frac{m_e}{v}\overline{\psi}\psi H$$

$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 32 years later... (stages of grief → 1982)

Hierarchy problem

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**	$-1/2$
$(e_R)^\dagger$	η^α	**1**	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x)+v}{\sqrt{2}}\right] \exp\left[i\frac{\tau^i}{2} G_i(x)\right]$	-	**2**	$1/2$

Depression



credit: quantumdiaries.org

$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W^{\mu\nu}_i - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda\left(\Phi^\dagger \Phi\right.$$

$$\Phi \to \Phi' = \exp\left[i\frac{\tau^i}{2}\theta_i(x)\right] \Phi = \frac{1}{\sqrt{2}}[H(x) + v]$$

$$\mathcal{L} = i\overline{\psi}\gamma^\mu \partial \psi - m_e \overline{\psi}\psi - i(\nu_L)^\dagger \overline{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2}\partial^\mu H \partial_\mu H + \frac{e}{\cos\theta_W \sin\theta_W} \overline{\nu_L}\nu_L Z_\mu + \cdots$$

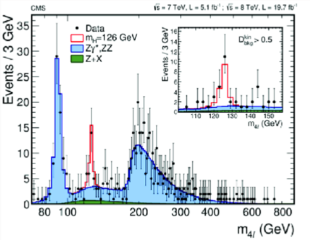
$$-\frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2}\right) + \left(m_W^2 W^{\mu -} W^+_\mu + \frac{1}{2} m_Z^2 Z^\mu Z_\mu\right)\left(1 + 2\frac{H}{v} + \frac{H^2}{v^2}\right) + \frac{m_e}{v}\overline{\psi}\psi H$$

$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - i g_2 \frac{\tau_i}{2} W^i_\mu - i g_1 B_\mu$: 62 years later... (stages of grief → 2012)

Higgs discovery!

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	**2**	$-1/2$
$(e_R)^\dagger$	η^α	**1**	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x)+v}{\sqrt{2}}\right] \exp\left[i\frac{\tau^i}{2} G_i(x)\right]$	-	**2**	$1/2$

Acceptance

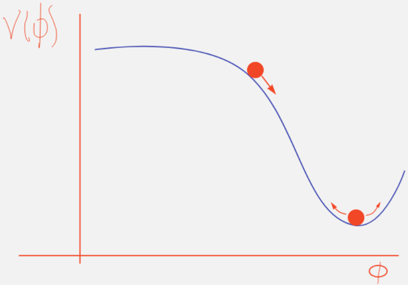


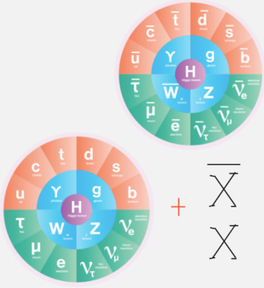
$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi$$

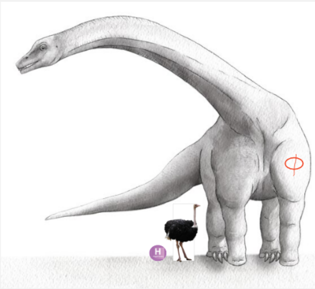
$$\Phi \to \Phi' = \exp\left[i\frac{\tau^i}{2}\theta_i(x)\right]\Phi = \frac{1}{\sqrt{2}}[H(x) + v]$$

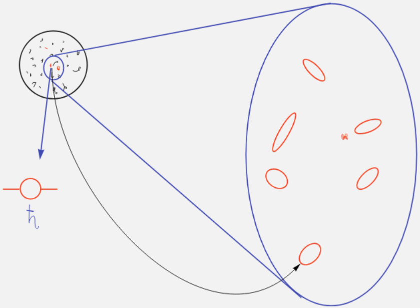
$$\mathcal{L} = i\overline{\psi}\gamma^\mu \partial \psi - m_e \overline{\psi}\psi - i(\nu_L)^\dagger \overline{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2}\partial^\mu H \partial_\mu H + \frac{e}{\cos\theta_W \sin\theta_W} \overline{\nu_L}\nu_L Z_\mu + \cdots$$

$$-\frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2}\right) + \left(m_W^2 W^{\mu -} W^+_\mu + \frac{1}{2} m_Z^2 Z^\mu Z_\mu\right)\left(1 + 2\frac{H}{v} + \frac{H^2}{v^2}\right) + \frac{m_e}{v}\overline{\psi}\psi H$$









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Jacobus Kapteyn - Wikipedia

Prof Jacobus Cornelius Kapteyn FRS FRSE LLD (19 January 1851 - 18 June 1922) was a Dutch astronomer. He carried out extensive studies of the Milky Way and was the discoverer of evidence for galactic rotation. Kapteyn was also among the first to suggest ...

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Fritz Zwicky - Wikipedia

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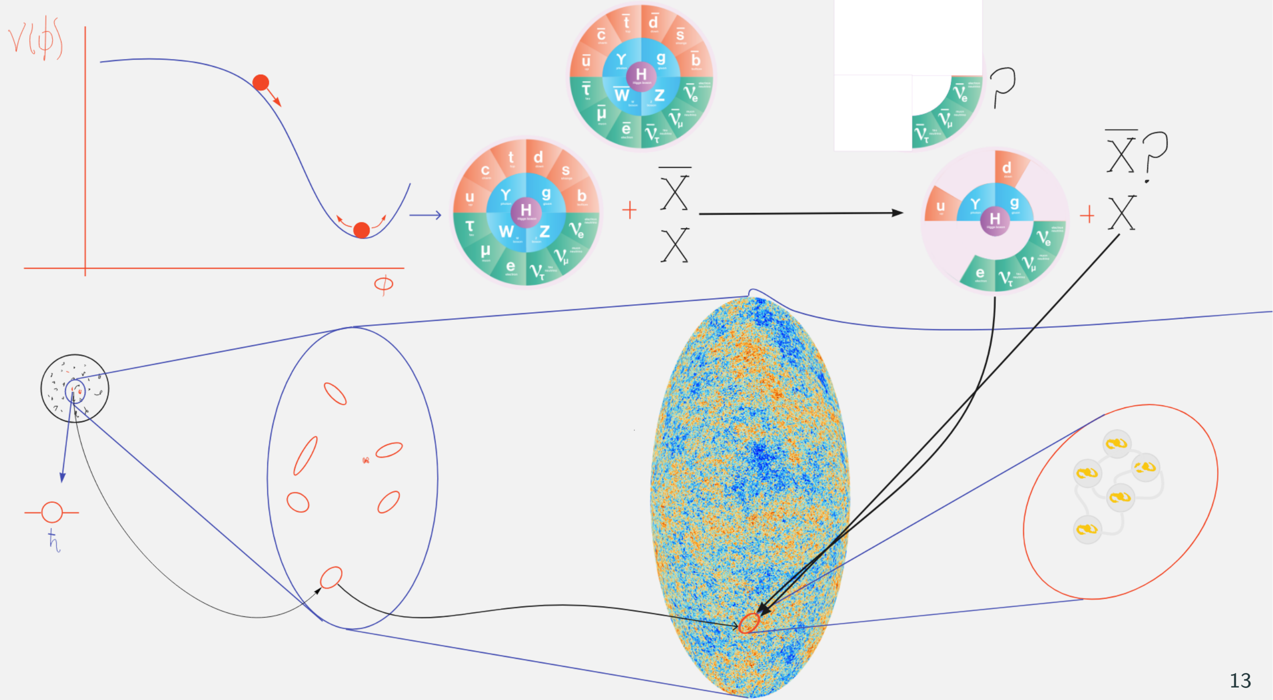
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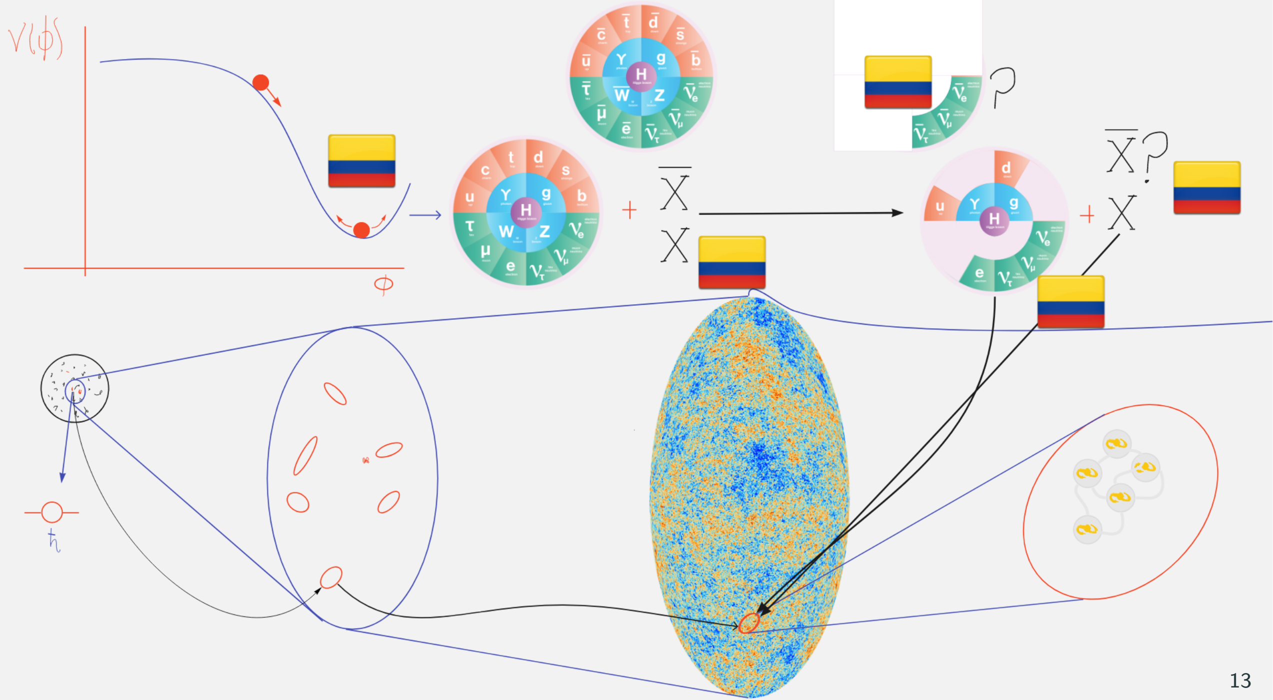

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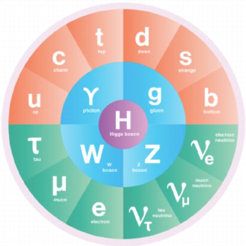
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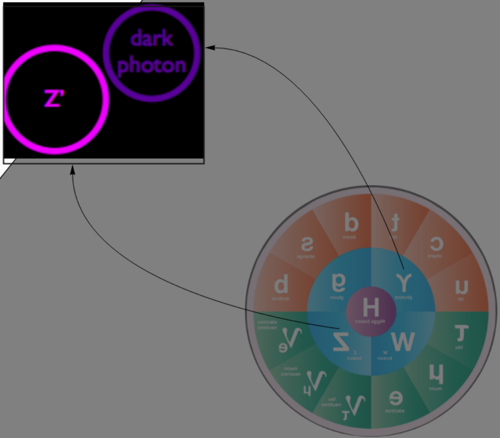
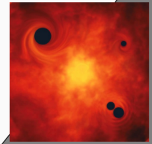
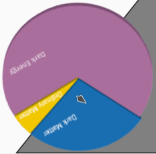
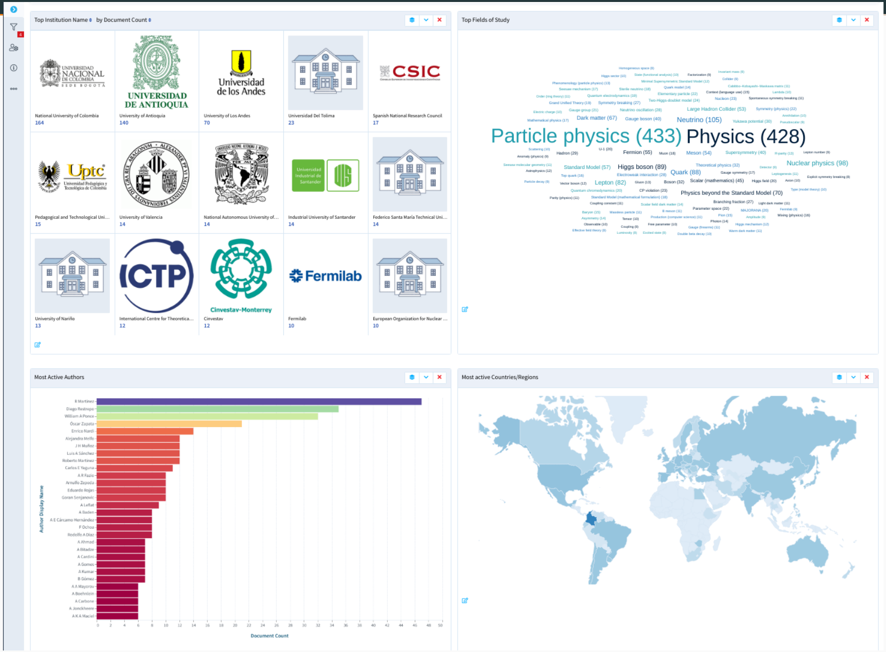

dark photon
Z'




Dark Energy
Ordinary Matter
Dark Matter

dark photon
Z'
t top
d down
c charm
s strange
u up
b bottom
γ photon
g gluon
H Higgs boson
W w boson
Z z boson
τ tau
μ muon
e electron
ν_e electron neutrino
ν_μ muon neutrino
ν_τ tau neutrino

Particle physics without hep-ex in Colombia in lens.org



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LATIN AMERICAN HECAP PHYSICS BRIEFING BOOK

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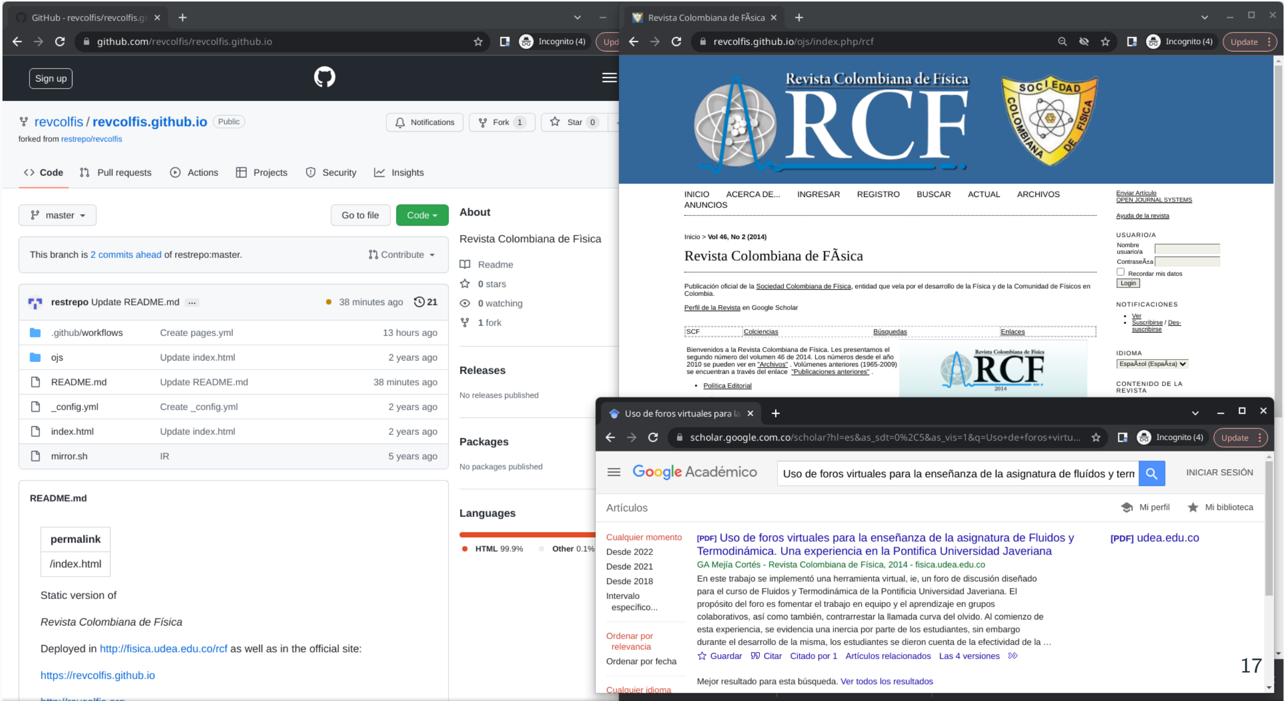
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Star 0
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Go to file
Code
This branch is 2 commits ahead of restrepo:master.
Contribute
restrepo Update README.md ... 38 minutes ago 21
.github/workflows Create pages.yml 13 hours ago
ojs Update index.html 2 years ago
README.md Update README.md 38 minutes ago
_config.yml Create _config.yml 2 years ago
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GA Mejía Cortés - Revista Colombiana de Física, 2014 - fisica.udea.edu.co
En este trabajo se implementó una herramienta virtual, ie, un foro de discusión diseñado para el curso de Fluidos y Termodinámica de la Pontificia Universidad Javeriana. El propósito del foro es fomentar el trabajo en equipo y el aprendizaje en grupos colaborativos, así como también, contrarrestar la llamada curva del olvido. Al comienzo de esta experiencia, se evidencia una inercia por parte de los estudiantes, sin embargo durante el desarrollo de la misma, los estudiantes se dieron cuenta de la efectividad de la ...
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Conclusiones

La consolidación experimental del modelo estándar abre nuevos retos a la enseñanza de la física contemporánea en los pregrados, donde se debería hacer más énfasis en las propiedades generales de las teorías clásicas de campos a la luz de los teoremas de Noether.