## The field content of the Standard Model (SM)

Covariant derivative

Field tensor

The SM Lagrangian = Sum of the kinetic terms

+ the Higgs potential

+ the Yukawa interaction terms

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Kinetic term

Adj.repr.

Field

**Vector bosons** 

Charge

U(I	$B(\gamma)$	$B_{\mu}, \ (B_{\mu} = B_{\mu}^{\dagger})$	<b>1</b> , <b>1</b> , 0	Weak	hypercha	rge, Y	$-\frac{1}{4}B_{\mu\nu}B^{\mu\nu}$	$D_{\mu} = \partial_{\mu} +$	$D_{\mu} = \partial_{\mu} + \dots + Y  \mathrm{i} g' B_{\mu} \qquad B_{\mu\nu} = B_{\mu\nu}$		$\partial_{[\mu}B_{\nu]}$			Т	The $SU(n)$ §	generators		
SU(	$(2)_{\rm L}$ $W^{\pm},$ $W^{3}(Z^{0})$	$W_{\mu}^{i}, i = 1, 2, 3$ $(W_{\mu}^{i} = W_{\mu}^{\dagger i})$	<b>1,3</b> ,0	Wea	ak isospin	$T^3$	$ \begin{array}{c} -\frac{1}{4}W_{\mu\nu}^{i}W^{i\mu\nu} = \\ -\frac{1}{2}\operatorname{Tr}(\boldsymbol{W}_{\mu\nu}\boldsymbol{W}^{\mu\nu}) \end{array} $		r - r		$+ ig[\boldsymbol{W}_{\mu}, \boldsymbol{W}_{ u}]$ $- g\epsilon^{ijk}W_{\mu}^{j}W_{ u}^{k}$	$\begin{array}{c} \boldsymbol{W}_{\mu} \equiv W_{\mu}^{i} t^{i} \\ \boldsymbol{W}_{\mu\nu} \equiv W_{\mu\nu}^{i} t \end{array}$		$\int$ SU(2) $\int$ $t^i$	$\equiv \frac{1}{2}  au^i$	$[t^i, t^i] = ie$ $Tr(t^i t^j) =$		
SU(	g	$G^{a}_{\mu}, \ a = 1,, 8$ $(G^{a}_{\mu} = G^{\dagger a}_{\mu})$	8,1,0		Color		$ \begin{array}{c} -\frac{1}{4}G^{a}_{\mu\nu}G^{a\mu\nu} = \\ -\frac{1}{2}\operatorname{Tr}(\boldsymbol{G}_{\mu\nu}\boldsymbol{G}^{\mu\nu}) \end{array} $		$+ + ig_s G_{\mu}$ $+ + ig_s G_{\mu\nu}$	$G_{\mu\nu} = 2\partial_{[\mu}G_{\nu]} + G^a_{\mu\nu} = 2\partial_{[\mu}G^a_{\nu]} - G^a_{\mu\nu} = 2\partial_{[\mu}G^a_{\nu]} - G^a_{\mu\nu}$		$G_{\mu} \equiv G_{\mu}^{a} T^{a}$ $G_{\mu\nu} \equiv G_{\mu\nu}^{a} T^{c}$		$\boxed{ \text{SU}(3) } T^a$	$= \pm \lambda^{a}$	$[T^a, T^b] = i$ $Tr(T^a T^b) = i$		
Fermions		Field	Repr.	$Q = T^3 + Y$			Kinetic term		Covariant derivative			Chirality projection: $\Psi$	$\equiv \left(\frac{\chi_{\alpha}}{\bar{\psi}^{\dot{\alpha}}}\right),$	$\boxed{\Psi^{ t L} \equiv P_{ t L} \Psi} =$	$=\begin{pmatrix} \chi_{\alpha} \\ 0 \end{pmatrix},  [$	$\Psi^{ extsf{R}} \equiv P_{ extsf{R}} \Psi$ =	$=\begin{pmatrix} 0 \\ \bar{\psi}^{\dot{\alpha}} \end{pmatrix}$	
Quarks	$u_{L}, (c_{L}, t_{L})$	$\Psi_{Q} = \begin{pmatrix} \Psi_{u}^{L} \\ \Psi_{d}^{L} \end{pmatrix}, \ \Psi_{Q}^{\dagger},$ $\Psi_{u}^{L} = P_{L} \Psi_{u}, \dots$	$oxed{egin{array}{c} oxed{3,2,+rac{1}{6}} \end{array}}$	+2/3	+1/2	+1/6	$\overline{oldsymbol{\Psi}_Q} \; \mathrm{i} \gamma^\mu D_\mu oldsymbol{\Psi}_Q$	$D_{\mu}\mathbf{\Psi}_{Q} = \left(\partial_{\mu} + ig_{s}\mathbf{G}_{\mu} + ig\mathbf{W}_{\mu} + \frac{1}{6}ig'B_{\mu}\right)\mathbf{\Psi}_{Q}$				Dirac						
	$d_{L},(s_{L},b_{L})$			$\left[\begin{array}{c} -1/3 \end{array}\right]$	$\begin{bmatrix} -1/2 \end{bmatrix}$	+1/6	$\mathbf{r}_{Q}$ $\mathbf{r}_{H}$ $\mathbf{r}_{Q}$					conjugate:	$\overline{\Psi} \equiv \Psi^{\dagger} \beta$ , $\beta \equiv \begin{pmatrix} 0 & \delta^{\alpha}{}_{\beta} \\ \delta_{\dot{\alpha}}{}^{\dot{\beta}} & 0 \end{pmatrix}$ , $\Psi^{\dagger} = (\bar{\chi}^{\dot{\alpha}} \ \psi_{\alpha})$ $\overline{\Psi} = (\psi_{\alpha} \ \bar{\chi}^{\dot{\alpha}})$					
	$u_{R},(c_{R},t_{R})$	$\Psi_u^{R} = P_{R} \Psi_u, \ \Psi_u^{R\dagger}$	$oxed{3,1,+rac{2}{3}}$	+2/3	0	+2/3	$\left( egin{array}{c} \overline{\Psi_u^{\scriptscriptstyle  extsf{R}}} \ \mathrm{i} \gamma^\mu D_\mu  \Psi_u^{\scriptscriptstyle  extsf{R}} \end{array}  ight)$	$D_{\mu}\Psi_{u}^{R}=\left(\partial_{\mu}\Psi_{u}^{R}\right)$	$g_{\mu} + \mathrm{i}g_{s}G_{\mu} + \boxed{\mathrm{i}g}$	$\Psi_{\mu} + \frac{2}{3} \mathrm{i} g' B_{\mu} \Psi_{u}^{R}$		Charge conjugate:	$egin{aligned} \Psi^{C} \equiv C_0 \Psi^* \ \end{pmatrix},  C_0 \equiv egin{pmatrix} 0 & arepsilon_{lpha\dot{eta}} & arepsilon \ arepsilon^{\dot{lpha}\dot{eta}} & 0 \end{pmatrix},  \Psi^{C} = egin{pmatrix} \psi_lpha \ ar{\chi}^{\dot{lpha}} \ \end{pmatrix}. \end{aligned}$				$\begin{pmatrix} \psi_{lpha} \\ ar{\chi}^{\dot{lpha}} \end{pmatrix}$	
	$d_{R},(s_{R},b_{R})$	$\Psi_d^{\rm R} = P_{\rm R} \Psi_d, \ \Psi_d^{\rm R\dagger}$	$oxed{3,1,-rac{1}{3}}$	$\left(-1/3\right)$	0	$\left[\begin{array}{c} -1/3 \end{array}\right]$	$\left( egin{array}{c} \overline{\Psi_d^{\sf R}} \ { m i} \gamma^\mu D_\mu  \Psi_d^{\sf R} \end{array}  ight)$	$D_{\mu}\Psi_{d}^{R}=\left(\partial_{\mu}^{R}\right)$	$_{\mu}+\mathrm{i}g_{s}G_{\mu}+\boxed{\mathrm{i}g}$	$\Psi_{\mu}$ $-\frac{1}{3}\mathrm{i}g'B_{\mu})\Psi_{d}^{R}$		conjugate.		$(D_{\mu}\Psi)^{c} = C_0$		,		
	$\bar{u}_{L} = (u_{R})^{C}, \dots$	$\Psi_{ar{u}}^{ t L} = P_{ t L} \Psi_{ar{u}}, \; \Psi_{ar{u}}^{ t L\dagger}$	$\overline{oldsymbol{3}}, oldsymbol{1}, -rac{2}{3}$	$\left(-2/3\right)$	0	$\left(-2/3\right)$	$\left( egin{array}{c} \overline{\Psi^{ t L}_{ar{u}}} \ { m i} \gamma^{\mu} D_{\mu}  \Psi^{ t L}_{ar{u}} \end{array}  ight)$	$D_{\mu}\Psi_{ar{u}}^{L}=\left(\partial_{\mu}\Psi_{ar{u}}^{L}\right)$	$g_{\mu} - \mathrm{i}g_{s}G_{\mu}^{*} - \mathrm{i}gH$	$\Psi_{\mu}^* + \frac{2}{3} i g' B_{\mu} \Psi_{\bar{u}}^{L}$	Trading R-			* complex cope 2-componer				
	$\bar{d}_{L} = (d_{R})^{C}, \dots$	$\Psi_{ar{d}}^{ extsf{L}} = P_{ extsf{L}} \Psi_{ar{d}}, \; \Psi_{ar{d}}^{ extsf{L}\dagger}$	$\overline{f 3}, {f 1}, + rac{1}{3}$	+1/3	0	+1/3	$\overline{\Psi_{ar{d}}^{\scriptscriptstyleL}} \; \mathrm{i} \gamma^\mu D_\mu  \Psi_{ar{d}}^{\scriptscriptstyleL}$	$D_{\mu}\Psi_{\bar{d}}^{L} = \left(\partial_{\mu}\Psi_{\bar{d}}^{L}\right)$	$g_{\mu}-\mathrm{i}g_{s}G_{\mu}^{*}-\mathrm{i}gV$	$\Psi_{\mu}^* - \frac{1}{3} i g' B_{\mu} \Psi_{\bar{d}}^{L}$	_	conjugated						
Leptons	$ u_{eL}, ( u_{\muL},  u_{\tauL}) $	$oldsymbol{\Psi}_L = egin{pmatrix} \Psi^{ t  t}_{ u_e} \ \Psi^{ t  t}_e \end{pmatrix}, \; oldsymbol{\Psi}^{ t  t}_L ,$	1.2 1	0	+1/2	$ \overline{ -1/2 } $	$\overline{oldsymbol{\Psi}_L}  \mathrm{i} \gamma^\mu D_\mu oldsymbol{\Psi}_L$	$D_{\mu} \boldsymbol{\Psi}_{L} = \left(\partial_{\mu} + \overrightarrow{ig}_{s} \boldsymbol{G}_{\mu}\right) + ig \boldsymbol{W}_{\mu} - \frac{1}{2} ig' B_{\mu} \boldsymbol{\Psi}_{L}$		ъ₩ <sup>1</sup> ;«/Р \Т-	)	$)^{c} = \begin{pmatrix} \psi_{\alpha} \\ \bar{\chi}^{\dot{\alpha}} \end{pmatrix},$		The electroweak charges				
	$e_{L},(\mu_{L}, au_{L})$	$\Psi^{L}_{ u_e} = P_{L} \Psi_{ u_e}, \dots$	$egin{array}{c} egin{array}{c} \egin{array}{c} \egin{array}{c} \egin{array}{c} \egin{array}{c} \egin{array}{c} \egin{array}$	-1	-1/2	$ \overline{ -1/2 } $	$oldsymbol{\Psi}_L$ 17° $D_{\mu}$ $oldsymbol{\Psi}_L$	$\int_{\mathcal{U}} \mathcal{L} = \left( O_{\mu} + \left[ \operatorname{ig}_{s} \mathcal{Q}_{\mu} \right] + \operatorname{ig}_{s} \mathcal{W}_{\mu} - \frac{1}{2} \operatorname{ig}_{s} D_{\mu} \right) \mathcal{L}$			$\Psi_{ar{u}}^{L} = P_{L}$	$\Psi_{ar{u}} =$						
	$ u_{eR}, (\nu_{\muR}, \nu_{\tauR}) $	$\Psi^{ extsf{R}}_{ u_e} = P_{ extsf{R}} \Psi_{ u_e}, \; \Psi^{ extsf{R}\dagger}_{ u_e}$	<b>1</b> , <b>1</b> , 0	0	0	0	$\overline{\Psi^{R}_{ u_e}} \ \mathrm{i} \gamma^\mu D_\mu  \Psi^{R}_{ u_e}$	$D_{\mu}\Psi_{\nu_{e}}^{L} = (\delta$	$\partial_{\mu} + \overline{ig_s G_{\mu} + ig}$	$W_{\mu} + ig'YB_{\mu} \Psi_{\nu_e}^{L}$	$=P_{L}(\Psi$	$(u_u)^{c} = \begin{pmatrix} \psi_{\alpha} \\ 0 \end{pmatrix},$	$\overline{e}_{\scriptscriptstyle  m L}$ $Y$		$U = H_{\overline{\overline{e}}_{ m R}}^+$		$W^{+}$	
	$e_{R},(\mu_{R}, au_{R})$	$\Psi_e^{\mathrm{R}} = P_{\mathrm{R}} \Psi_e, \; \Psi_e^{\mathrm{R}\dagger}$	1, 1, -1	-1	0	-1	$\overline{\Psi_e^{R}} \; \mathrm{i} \gamma^\mu D_\mu  \Psi_e^{R}$	$D_{\mu}\Psi_{e}^{R} = \left(\partial_{\mu} \Psi_{e}^{R}\right)$	$\mu + ig G_{\mu} + ig V$	$V_{\mu}$ $-\mathrm{i} g' B_{\mu} \Psi_e^{R}$	$(\Psi_u^{R})^{C} = \left( \hat{eta}_u^{R} \right)^{C}$	$(\Psi_u^{R})^{C} = \begin{pmatrix} \psi_\alpha \\ 0 \end{pmatrix}  \Longrightarrow \qquad \qquad u$			$u_1$	L d	$T^3$	
	$\bar{\nu}_{eL} = (\nu_{eR})^{C}, \dots$	$\Psi^{L}_{ar{ u}_e} = P_{L} \Psi_{ar{ u}_e}, \; \Psi^{L\dagger}_{ar{ u}_e}$	<b>1</b> , <b>1</b> , 0	0	0	0	$\overline{\Psi^{L}_{ar{ u}_e}} \ \mathrm{i} \gamma^\mu D_\mu  \Psi^{L}_{ar{ u}_e}$	$D_{\mu}\Psi_{\bar{\nu}_{e}}^{L} = (\delta_{e})^{L}$	$\partial_{\mu} - \overline{\mathrm{i}g_{s}G_{\mu}^{*} - \mathrm{i}g}$	$W_{\mu}^* + ig'YB_{\mu} \Psi_{\bar{\nu}_e}^{L}$	$\Psi_{\bar{u}}^{L} = (\Psi_{u}^{R})^{C},$ i.e. $\bar{u}_{L} = (u_{R})^{C}$			$\overline{d}_{ ext{ iny L}}$				
	$\bar{e}_{L} = (e_{R})^{C}, \dots$	$\Psi_{ar{e}}^{ t L} = P_{ t L} \Psi_{ar{e}}, \; \Psi_{ar{e}}^{ t L \dagger}$	(1, 1, +1)	+1	0	+1	$\overline{\Psi_{ar{e}}^{\scriptscriptstyle L}} \ \mathrm{i} \gamma^\mu D_\mu  \Psi_{ar{e}}^{\scriptscriptstyle L}$	$D_{\mu}\Psi_{ar{e}}^{\mathtt{L}} = \left(\partial_{\mu} - \overrightarrow{\mathrm{lg}_{s}G_{\mu}^{*}} \cdot igW_{\mu}^{*}\right) + ig'B_{\mu}\Psi_{\mu}^{\mathtt{L}}$		$\Psi_{\mu}^* + \mathrm{i} g' B_{\mu} \Psi_{\bar{e}}^{L}$		H.	70	γ̈́	3	Н	$H^{0\dagger} igotimes_{oldsymbol{\mathcal{V}}_{\mathrm{L}}}$	
CII		Tr. 11	D								)		$\overline{oldsymbol{v}}_{ m R}$	$Z^{\scriptscriptstyle 0}$			$\overline{} u_{\scriptscriptstyle m L}$	
	Scalar boson	Field  (H+)	Repr. $1, 2, +\frac{1}{2}$	Q	$T^3$	Y 1/2	Kinetic term	Covariant derivative $D_{\mu} \boldsymbol{\Phi} = \left(\partial_{\mu} + \overrightarrow{ig_s} \boldsymbol{G}_{\mu}\right) + ig \boldsymbol{W}_{\mu} + \frac{1}{2} ig' B_{\mu} \boldsymbol{\Phi}$ $(D_{\mu} \boldsymbol{\Phi})^* = \left(\partial_{\mu} - \overrightarrow{ig_s} \boldsymbol{G}_{\mu}^*\right) - ig \boldsymbol{W}_{\mu}^* - \frac{1}{2} ig' B_{\mu} \boldsymbol{\Phi}^*$			The neutral Higgs field which breaks the EW symmetry. $(H^\pm,H^{0\dagger} \text{ are eaten by } W^\pm,Z^0)$ $\overline{u}_{\rm R}$ $\overline{u}_{\rm L}$							
Higgs	$H^+, H^-$	$oldsymbol{\Phi} = egin{pmatrix} H^+ \ H^0 \end{pmatrix}, \; oldsymbol{\Phi}^\dagger,$		+1	+1/2	+1/2	$(D_{\mu}\mathbf{\Phi})^{\dagger}D^{\mu}\mathbf{\Phi}$											
	$H^0,H^{0\dagger}$	$\Phi^{\dagger} = \begin{pmatrix} H^{-} & H^{0\dagger} \end{pmatrix}$		0 sentation (	$\int_{0}^{1} \frac{-1/2}{\widetilde{\Phi} \text{ is } (1)}$	$\boxed{+1/2}$ $\overline{2}$ $-\frac{1}{2}$												
,				)	entation of $\widetilde{\Phi}$ is $(1, \overline{2}, -\frac{1}{2})$ .					iggs potential				$e_{\scriptscriptstyle  m L}$		OR —		
The interaction terms  The interactions between the gauge bosons and the other fields				The Yukawa interaction terms				$\mathcal{L}^{\mathrm{H}} = -\mu^{2}\Phi^{\dagger}\Phi - \lambda(\Phi^{\dagger}\Phi)^{2}$			$ \begin{pmatrix} W_{\mu}^{+} \\ W_{\mu}^{-} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & -i \\ i & 1 \end{pmatrix} \begin{pmatrix} W_{\mu}^{1} \\ W_{\mu}^{2} \end{pmatrix},  \begin{pmatrix} Z_{\mu} \\ A_{\mu} \end{pmatrix} = \begin{pmatrix} \cos \theta_{W} & -\sin \theta_{W} \\ \sin \theta_{W} & \cos \theta_{W} \end{pmatrix} \begin{pmatrix} W_{\mu}^{3} \\ B_{\mu} \end{pmatrix} $							
(fermions and Higgs) all arise from the gauge covariant derivatives. The self-interactions of the nonabelian gauge bosons are all contained in their kinetic terms. The interactions between the fermions and the Higgs field are all given by Yukawa terms (on SSB, these terms generate the fermion masses).				+	-		$\begin{split} &\Psi_{d_J}^{R} + y_u^{IJ} \left( \overline{\Psi_{Q_I}^{L}}  \widetilde{\Phi} \right) \Psi_{d_J}^{R} \\ &+ y_{\nu}^{IJ} \left( \overline{\Psi_{L_I}^{L}}  \widetilde{\Phi} \right) \Psi_{\nu_J}^{R} + \end{split}$		For <b>SSB</b> : $\mu^2 <$ vev: $\langle \Phi^{\dagger} \Phi$	$<0$ and $\lambda>0$ $\Phi \Big>_{\min}=rac{v^2}{2},  v=\sqrt{2}$								
					where $\widetilde{\Phi} \equiv (-i\tau^2)^{T} \Phi^*$ , (Note: $\Phi_d = \Phi$ , $\Phi_u = \widetilde{\Phi}$ ) and the indices $I, J = 1, 2, 3$ run over generations unitary g.: $\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + \sigma(x) \end{pmatrix}$ , $\Phi_0 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$ $\sin \theta_W \equiv \frac{g'}{\sqrt{g^2 + g'^2}}$ , $\cos \theta_W \equiv \frac{g}{\sqrt{g^2 + g'^2}}$													