

The SU(5) Grand Unified Theory

P. Eliasson, E. Thomé

Uppsala University

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Outline

The SU(5) Grand
Unified Theory

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Standard Model

SU(5) unification

Breaking of
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Physical
consequences

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- 4 Physical consequences

Standard Model

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■ SU(3)×SU(2)×U(1)

- Quarks triplets under SU(3), left-handed particles and right-handed anti-particles doublets under SU(2).

- First generation right-handed particles:

$$u^\dagger : (3, 1)_{2/3}, \quad d^\dagger : (3, 1)_{-1/3}, \quad e^\dagger : (1, 1)_{-1},$$
$$\bar{\psi}^\dagger : (\bar{3}, 2)_{-1/6}, \quad \bar{l}^\dagger : (1, 2)_{1/2}$$

- SU(3)×SU(2)×U(1) representation:

$$(3, 1)_{2/3} \oplus (3, 1)_{-1/3} \oplus (1, 1)_{-1} \oplus (\bar{3}, 2)_{-1/6} \oplus (1, 2)_{1/2}$$

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- Fundamental representations 5 and $\bar{5}$



$$(3, 1)_{2/3} \oplus (3, 1)_{-1/3} \oplus (1, 1)_{-1} \oplus (\bar{3}, 2)_{-1/6} \oplus (1, 2)_{1/2}$$

- Generators:

$$\begin{pmatrix} T_a & 0 \\ 0 & 0 \end{pmatrix}, \quad \begin{pmatrix} 0 & 0 \\ 0 & R_a \end{pmatrix}, \quad \begin{pmatrix} -1/3 & 0 \\ 0 & I/2 \end{pmatrix}$$

- SU(5) multiplet:

$$\begin{pmatrix} d_r \\ d_g \\ d_b \\ \bar{e} \\ \bar{\nu} \end{pmatrix}$$

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- Remaining ten-dimensional part:

$$(3, 1)_{2/3} \oplus (3, 1)_{-1/3} \oplus (1, 1)_{-1} \oplus (\bar{3}, 2)_{-1/6} \oplus (1, 2)_{1/2}$$

- SU(5) has two ten-dimensional representations 10 and $\bar{10}$, where $\bar{10} = \bar{5} \otimes_{AS} \bar{5}$

-

$$\begin{aligned} [(\bar{3}, 1)_{1/3} \oplus (1, 2)_{-1/2}] \otimes_{AS} [(\bar{3}, 1)_{1/3} \oplus (1, 2)_{-1/2}] &= \\ &= [(3, 1)_{2/3} \oplus (1, 1)_{-1} \oplus (\bar{3}, 2)_{-1/6}] \end{aligned}$$

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- Right-handed particles: $5 \oplus \bar{10}$
- Left-handed particles: $\bar{5} \oplus 10$
-

$$\begin{pmatrix} d_r \\ d_g \\ d_b \\ \bar{e} \\ \bar{\nu} \end{pmatrix}, \quad \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & u_b & -u_g & -\bar{u}_r & -\bar{d}_r \\ -u_g & 0 & u_r & -\bar{u}_g & -\bar{d}_g \\ u_g & -u_r & 0 & -\bar{u}_b & -\bar{d}_b \\ \bar{u}_r & \bar{u}_g & \bar{u}_b & 0 & e \\ \bar{d}_r & \bar{d}_g & \bar{d}_b & e & 0 \end{pmatrix}$$

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- The 24 adjoint representation with vacuum values in the S direction breaks SU(5) into SU(3)×SU(2)×U(1)



$$24 \rightarrow (8, 1)_0 \oplus (1, 3)_0 \oplus (1, 1)_0 \oplus (3, 2)_{-5/6} \oplus (\bar{3}, 2)_{5/6}$$

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Mass generation

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- In order for a fermion to get mass in the SU(5) theory, the product of the representation containing the fermion and the representation containing the anti-fermion must include a component which transforms like the $SU(3) \times SU(2) \times U(1)$ Higgs field, i.e. $(1, 2)_{1/2}$, or its complex conjugate.
- Right-handed d quarks and positrons:

- $5 \otimes \overline{10} = \overline{5} \oplus \overline{45}$
- Both 5 and 45 contains $(1, 2)_{1/2}$

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$$\begin{array}{c}
 \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \square \\ \hline \end{array} \otimes \begin{array}{|c|} \hline a \\ \hline b \\ \hline c \\ \hline \end{array} = \left(\begin{array}{|c|c|} \hline \square & a \\ \hline \square & \\ \hline \square & \\ \hline \end{array} \oplus \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \square \\ \hline a \\ \hline \end{array} \right) \otimes \begin{array}{|c|} \hline b \\ \hline c \\ \hline \end{array} = \\
 \\
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- $10 \otimes 10 = 5 \oplus 45 \oplus 50$
- 50 does not contain $(1, 2)_{1/2}$

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■ Quark charges:

$$Q(\bar{\nu}) + Q(e^+) + 3Q(d) = 0 \quad \Rightarrow \quad Q(d) = -\frac{1}{3}Q(e^+)$$

- Weinberg angle: $\sin^2 \theta_W \approx 0.21$
- Unification of coupling constants at $\approx 10^{15}$ GeV
- Proton decay

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