

Electric Charge Breaking

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Why?

Why?

The Standard Model does not forbid it!

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The Standard Model does not forbid it!

Many experimental measurements, but theory landscape not explored to the same degree

We want to quantify how well we know the Standard Model gauge group

How?

How?

Add a charged scalar
to the Standard
Model

How?

$$(1, 1)_1$$

$$(3, 3)_{-1/3}$$

$$(1, 3)_1$$

Add a charged scalar
to the Standard
Model

$$(1, 2)_{1/2}$$

$$(1, 1)_2$$

$$(3, 2)_{1/6}$$

How?

$(1, 1)_1$

$(3, 3)_{-1/3}$

$(1, 3)_1$

Add a charged scalar
to the Standard
Model



Have it develop a
(small) vev

$(1, 2)_{1/2}$

$(1, 1)_2$

$(3, 2)_{1/6}$

Consequences?

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The photon
becomes
massive

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Boson- &
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...

Thank you for listening!

Poster Number

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Charge Breaking Framework

Why break electric charge?

- To provide further specification of how well we know the standard model (SM) gauge physics.
- In addition to further testing the SM, this also gives **limits and constraints on new physics**.
- There is an inherent tension against charged vacuum expectation values (vevs). In fact, the SM vacuum is already charged under a U(1) gauge group (i.e., hypercharge).
- While there are many representations/representations breaking the breaking of U(1), (e.g. $M_2 \sim 10^7 \text{ TeV}$), the theoretical side has not been studied in smaller detail.

$SU(3) \times SU(2) \times U(1)$
SM

extended scalar sector
with charged vevs

$SU(3) \times$
Colour groups and
broken symmetries

Motivation [2]:

We add a general set of new charged scalars ϕ_i to the SM and let these obtain vevs via the spontaneous symmetry breaking. In principle there can be any number of components of arbitrary charge. We study a distinction between charge representations that allow for renormalizable interactions and **minicharges**.

- Contribution to gauge boson masses

$$M_{ij}^2 = \sum_k \langle \phi_k | Q_i | \phi_k \rangle \langle \phi_k | Q_j | \phi_k \rangle$$
 for the mixing, with hypercharge q_i and Q_i representable on ϕ_i . The weak mixing angle θ will also be slightly different from the SM.

Distinct interactions

- SM doublets and singlets can mix as they have the same charge in the broken phase (i.e., they are both uncharged under $SU(3)_C$).
- They form new scalar and interaction operators, which are the doublets and singlets, not seen in the SM.

New Renormalizable Interactions

- We give a scalar with a given representation that allows for coupling to fermions, e.g. $(\mathbf{3}, \mathbf{1}, \frac{1}{6})$, vevs. The fermions that couple to it can then change their "flavour" in the broken phase by interaction with the vevs.
- Since the **lepton mix character only in the broken phase**, we need to rotate these into the new mass basis with the small angles θ_i , δ , and β .



- Because the weak mixing angle has contributions from the new vevs, the U(1) and SU(2) parts of the SM electric charge (or q^2 and q in a general representation) are **no longer set equal any more**.
- The change of basis also transforms the matrix that describes the interaction between fermions and photons. To first order we get:

$$\begin{pmatrix} \dots & \dots \\ \dots & \dots \end{pmatrix} \rightarrow \begin{pmatrix} \dots & \dots \\ \dots & \dots \end{pmatrix} + \begin{pmatrix} \dots & \dots \\ \dots & \dots \end{pmatrix} A \begin{pmatrix} \dots \\ \dots \end{pmatrix}$$

Minicharges

- A scalar ϕ_i may give us a new charge as U(1) operators are continuous. We may consider, e.g., some **small charges** $q_i \leq e$ compared to existing numbers to quantized values that give distinct interactions (although the following also holds in these cases).
- We define electric charge in the unbroken sector by the presence of the photon to obtain a **New Gell-Mann-Nishijima type formula**:

$$Q = \frac{1}{2} Y + \sum_i n_i \langle \phi_i | Q_i | \phi_i \rangle$$
 where the approximation holds for small charges.
- We have defined the dimensionless parameter n_i that can be used to characterize a model:

$$n_i \equiv \frac{q_i}{e} \frac{\langle \phi_i | Q_i | \phi_i \rangle}{\langle \phi_i | Y | \phi_i \rangle} \leq 1.61 \cdot 10^{-6}$$
- The limits have been derived from constraints charge non-renormalization.
- With this definition, we have **small charge representations** for the SM particles:

| Particle name | SM charge q_i [e] | Charge q_i under Q_i |
|------------------------|---------------------|---|
| neutrinos ν | 0 | $\frac{1}{2} Y = \frac{1}{2}$ |
| u quarks u | $\frac{2}{3}$ | $\frac{1}{2} Y + \frac{1}{3} = \frac{5}{6}$ |
| d quarks d | $-\frac{1}{3}$ | $\frac{1}{2} Y + \frac{1}{3} = \frac{5}{6}$ |
| W^\pm bosons W^\pm | ± 1 | $\frac{1}{2} Y = \frac{1}{2}$ |

Same representations

- Different kinds of vevs can arise:
 - Chargeless in SM context, and dependent on θ_i , δ , and β .
 - New higher-multiplet vanishing vevs, dependent on $(\theta_i + \delta)$.
 - New higher-multiplet violating vevs, dependent on $(\theta_i - \delta)$ or β .
- In fact we have considered only the first representation of leptons. The representation of matter interesting for this case:

$$(\mathbf{3}, \mathbf{1}, \frac{1}{6}), (\mathbf{3}, \mathbf{1}, \frac{1}{3}), (\mathbf{3}, \mathbf{1}, \frac{2}{3}), (\mathbf{3}, \mathbf{1}, \frac{5}{6})$$

Electron Decay



- When electric charge does not need to be conserved, there are lighter particles for the electron than for the photon and the neutrino (and anti-matter, as the lighter number can be broken).
- The neutrino photon has an **additional third polarization**. This means that observables dependent on the photon coupling need not necessarily go unmodified in the SM limit for $M_i \rightarrow 0$.
- We can compute the electron lifetime:

$$\tau = \frac{M_i^2}{4\pi \alpha^2 M_W^2 M_i^2} \approx 1.4 \cdot 10^{16} \frac{M_i^2}{M_W^2 M_i^2} \text{ s}$$
- It is proportional to the size of the scalar with representation $(\mathbf{3}, \mathbf{1}, \frac{1}{6})$ and M_i is the vev of $(\mathbf{3}, \mathbf{1}, \frac{1}{6})$.
- Even so lower from measurements that $M_i \leq 10^{16} \text{ GeV}$ and $\tau(e) \geq 4 \cdot 10^{26} \text{ s}$, this would mean $M_i \cdot M_W \leq 8.7 \cdot 10^{14} \text{ GeV}^2$.
- Having these representations with non-zero vevs at present time **would require extreme fine-tuning**.

References

[1] Peter Garza, Manuel Lujan, and Manuel Salewski. "Building new theories for decaying charge non-conservation" (in preparation).